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AUTHOR Campbell, Clifton P.
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ABSTRACT

This combination text and workbook is intended to introduce industrial arts students to numerical control part programming. Discussed in the first section are the impact of numerical control, training efforts, numerical control in established programs, related information for drafting, and the Cartesian Coordinate System and dimensioning techniques. The next three sections consist of series of tab sequential, variable block, and fixed block exercises. Covered in the fifth section are various types of design and drafting, production, and inspection and testing equipment. A glossary is appended. (MN)

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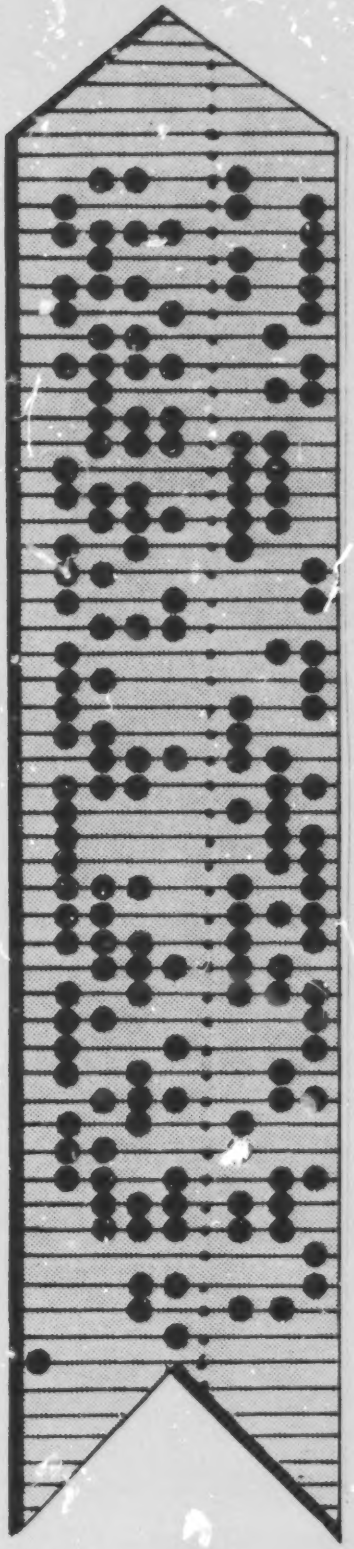

An Introduction to Numerical Control

PROBLEMS FOR NUMERICAL CONTROL PART PROGRAMMING

Clifton P. Campbell
Knoxville, Tennessee
January 1985

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Section I

A RATIONALE

One of the relationships between education and occupations is that the former provides the major qualifications for careers in the latter. It, therefore, follows that Industrial Arts has a responsibility to introduce young people to the complexities of a dynamic computerized industrial society. One of the accompanying important challenges is to familiarize students with meaningful and rewarding career opportunities in contemporary occupations, such as numerical-control technology.

Impact of Numerical Control

Less than a decade ago there were few numerical control (N/C) machines in manufacturing. Today the builders of N/C machines for drafting, industrial production, inspection and testing, and other manufacturing operations are selling "Cybernation" as the direct control of the entire manufacturing enterprise from idea to finished product.

With N/C we are in the fascinating era of direct communication with machines. Machines have traditionally been thought of as being an extension of "man's hand" - with N/C the concept goes further. The role of N/C is the extension of man's mind and hands through a machine.

Designers can now sketch a part on the screen of a cathode ray tube with a light pen. On command a computer will refine the sketch into an engineering drawing, fully dimensioned - after having performed a complete range of analyses.

From this computer process, different types of input media are produced which will control machines that manufacture and inspect the workpiece. In this way numerical control has created an interdependency of all the steps in the manufacturing sequence, from part conceptualization through the process that yields

a finished product.

Since its commercial introduction in 1955, applied research and development have continued to advance numerical-control technology. In particular the reliability of control components has increased. Special systems for a variety of specific machine applications have been devised. A wide range of competing units featuring varying combinations of electronic, electrical, hydraulic, optical and pneumatic control devices have become available. These replace earlier mechanical apparatus such as hand cranks, gear trains, cams and levers.

Such refinements in N/C hardware and integration with the computer have changed the basic concepts of manufacturing. Near revolutionary in terms of added capabilities and economics, N/C is making a significant impact on the industrial community.

The growing acceptance and substantial use of N/C in manufacturing has created a need for a work force with new and more advanced skills. As older conventional manufacturing equipment is replaced with N/C units, the demand for trained and upgraded workers continues to rise. This shift toward N/C in manufacturing makes necessary an awareness of its implications for manpower planning and a familiarization with the changing education requirements the new technology is imposing.

Industries which are involved in extensive manufacturing change include: (a) textiles, (b) electric machinery, (c) synthetic materials, (d) paper, (e) metals, (f) transportation, (g) aerospace, and (h) electric power. Competition, the complexities of production, the volume of business and the general application of research results have fostered the introduction of N/C technology in these as well as other industries.

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Training Efforts

Lacking available trained personnel in the labor market, employers have as a rule filled N/C positions by retraining their own employees. Varying degrees of training are needed to prepare these selected workers for the different skill and knowledge requirements associated with N/C. Substantially more training is required for programming and maintenance personnel than for machine operations. A different type of training is necessary for designers, engineers, managers and supervisors than for those who work directly with the equipment.

The tasks associated with numerical control require the development of unified and broader-based training efforts. Historically, equipment producers and users have been the principle sources of training. Nevertheless they naturally hesitate to spend lavishly on such training, because the results of a good program may be the loss of one's workers to rival manufacturers.

Programs in the academic community have been somewhat slow to develop. However, many universities, colleges, technical institutes, community colleges, vocational schools and correspondence schools are now beginning to contribute significantly to the total training effort.

There are few aspects of industrial production where more ideas are developing and new equipment being utilized than in the field of numerical control. It is perhaps the most rapidly expanding facet of industrial production, with applications ranging from the smallest machine shop to the largest assembly or manufacturing facilities. The use of numerical control is spreading, if for no other reason than the basic economics of manufacturing. It has not come to us without manpower needs and adjustments, any more than did previous technological innovations.

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Numerical Control in Established Programs

The logical beginning for a broad based training effort is an industrial arts program. Here students can be acquainted with the principles and applications of N/C just as they are with other technological innovations affecting industry.

One of the more promising approaches to including instruction on N/C technology in established programs is through related information. This is particularly appropriate in drafting, machine and electronics programs because of the dependency of N/C on principles long taught in these specializations. The significant impact of N/C machines on these specializations is another reason for the appropriateness of instructional effort.

The related information approach can be implemented without expensive new equipment or intensive curriculum planning. A drafting teacher, for example, would continue to teach the recognized course of study but use related information to reinforce the basic principles being taught. The resulting enriched learning experience would improve a student's understanding of contemporary drafting and manufacturing.

Related Information for Drafting

Many machine drafters would agree that one measure of their competency is a knowledge of manufacturing operations. This specialized knowledge is particularly important when deciding on the technique to be used in dimensioning a drawing.

When conventional machine tools are used in manufacturing a workpiece, the technique of dimensioning used by the drafter can influence the procedures followed by the machinist. This is the case when a dimensioned drawing predetermines the approach to manufacturing a workpiece. Recognition of this situation provides a rationale for teaching conventional dimensioning.

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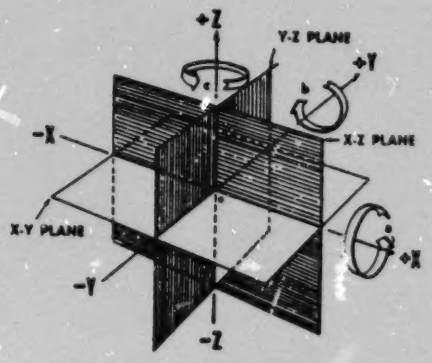
When N/C machine tools are to be used, the drafter utilizes either the absolute or incremental dimensioning technique rather than the conventional approach. Here then is an ideal opportunity to use related information concerning N/C to revitalize instruction on the basic principles of absolute and incremental dimensioning techniques.

The Cartesian Coordinate System and Dimensioning Techniques

Since most machine movements are at right angles to each other and movement must be calculated from a fixed reference, the Cartesian coordinate system is used (see Figure 1 below).



Cartesian Coordinates with Mutual Planes & Corresponding Angles

FIGURE 1

This system provides a means for locating positions from fixed planes or lines, in either absolute or incremental distances. These axes and planes become the references for machine motion. Generally, the first and most important motion of a machine is its travel from left to right with respect to the operator's work position. This is referred to as the X axis. Similarly, movement toward or away

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from th operator is referred to as the Y axis. This fixes the X-Y plane as horizontal and the Z axis as perpendicular for rise and fall.

The Cartesian coordinate system illustrated in Figure 1 shows that axes X, Y and Z intersect at a common point. This point is the reference location for direction and is called the origin or absolute zero reference. On each axis and on either side of zero, equal distances can be scribed and given unit values. Since the unit values are the same on either side of zero, it is necessary to define the unit value one has reference to. Algebraic signs, plus and minus, are used to make the position distinction. They indicate a direction from the zero point along the X, Y and Z axes. The origin or absolute zero reference could be fixed by the machine builder. Where this is done all motions begin at that position.

Either absolute or incremental dimensioning can be used for locating coordinate positions. Absolute dimensioning employs a fixed zero reference point or origin, and all dimensions are located with respect to that point. When programming a workpiece to be manufactured by an 'absolute' N/C system, a drawing dimensioned using the absolute or base line technique is important. Figure 2 is a drawing with absolute dimensioning.

Many point-to-point N/C systems utilize the absolute method of dimensioning to obtain motion and position in all axes. When numbers increase in one direction, motion takes place in that direction. The direction of motion reverses itself when the magnitude of the numbers decreases. This method eliminates the use of algebraic signs to indicate direction.

Incremental locations are given in terms of distance and direction from the origin or immediately preceding position to the next position desired. Unlike absolute dimensioning there is no common reference point for all dimensions in the incremental system. Figure 3 is an example of a drawing dimensioned using the

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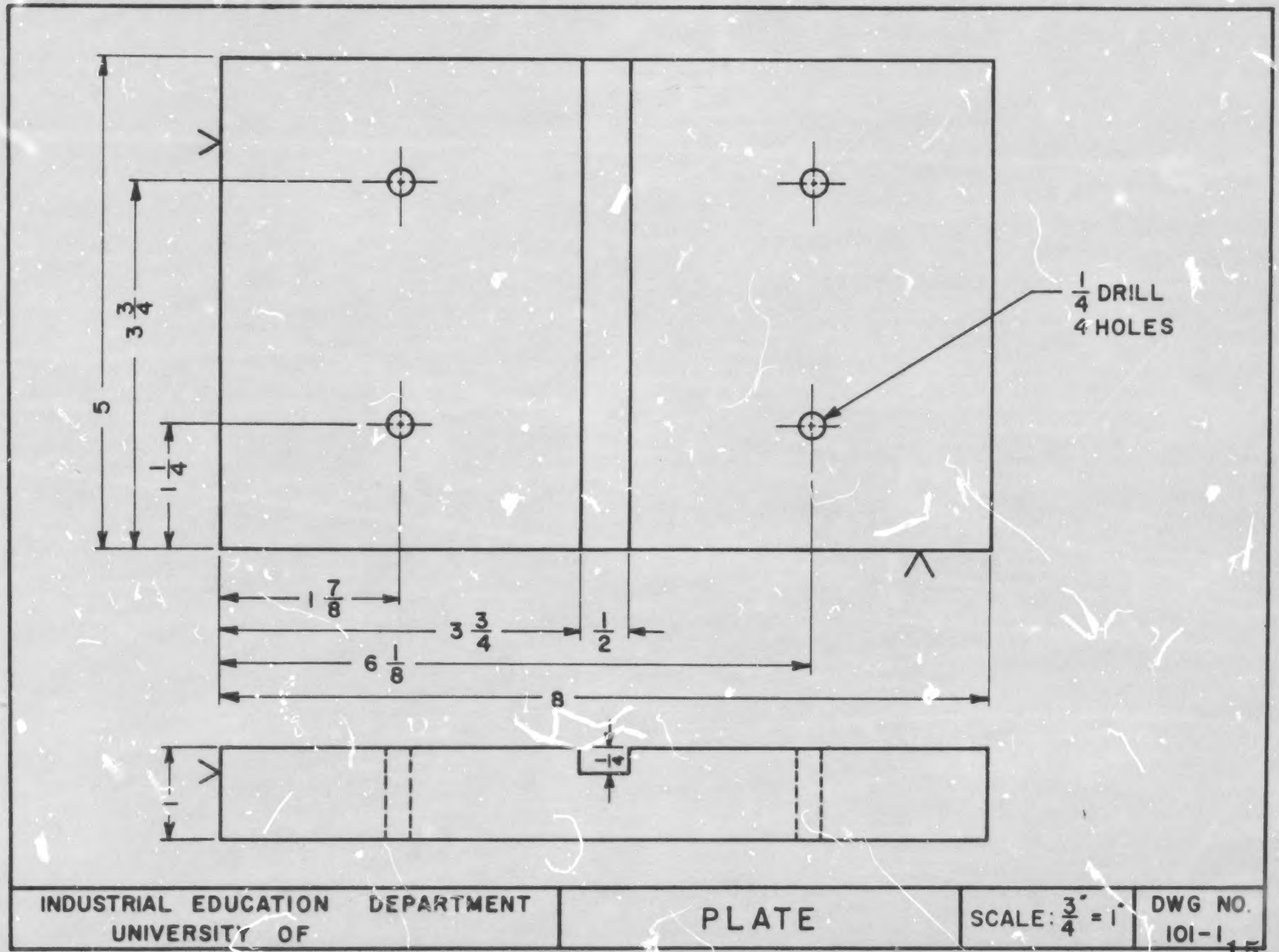

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FIGURE 2

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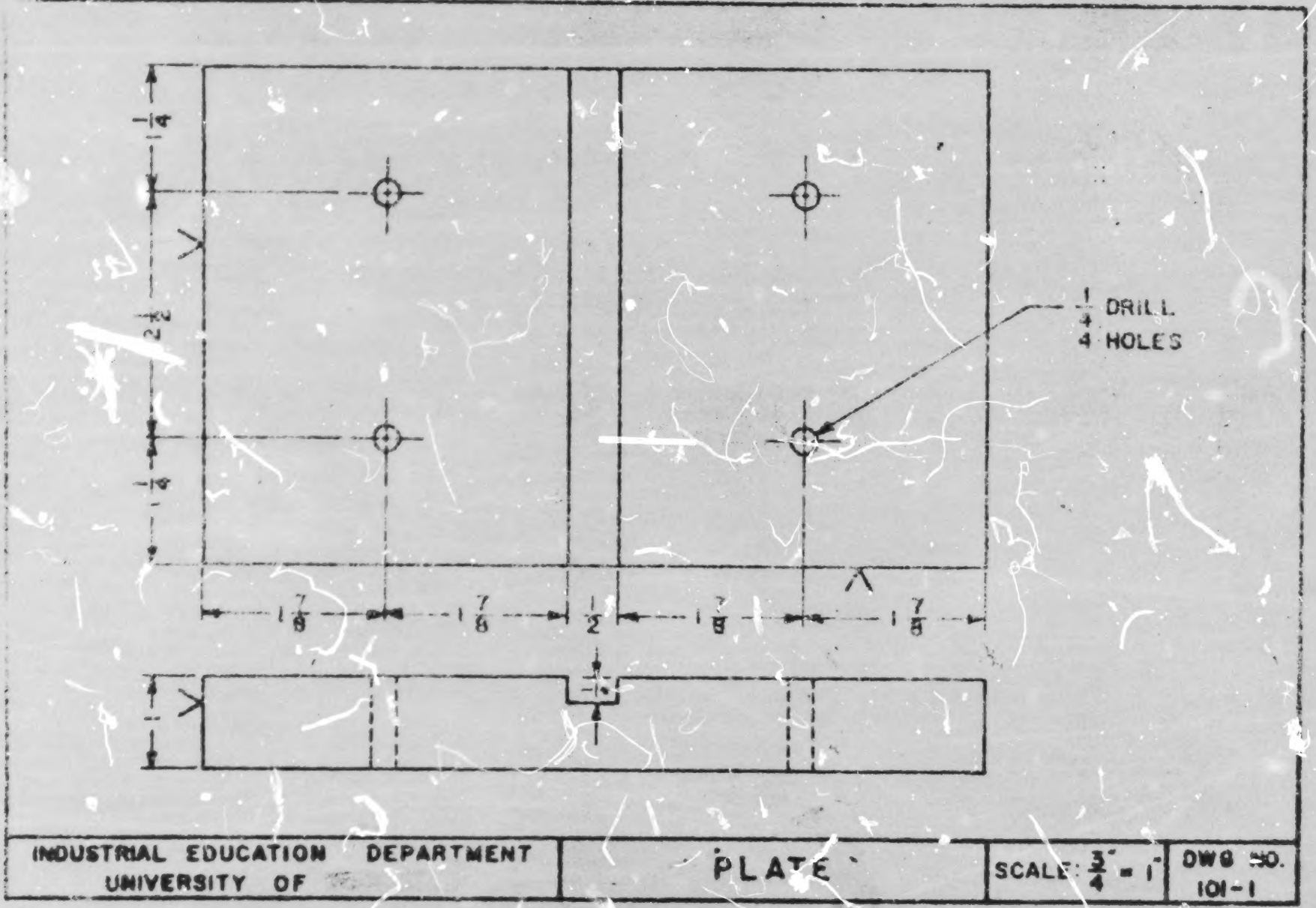

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FIGURE 3

incremental technique.

Most continuous path N/C systems use incremental dimensioning to obtain motion and position. The use of plus and minus designations takes on an entirely new significance when used in the incremental mode. A 'plus X' command directs the machine table to move 'right' along the X axis. Likewise a 'minus X' command directs the machine table to the 'left'. A 'plus Y' indicates 'move in' from the present location and a 'minus Y' commands a 'move out'. A 'plus Z' is a command to 'move away' from the part and a 'minus Z' commands the tool toward or into the part.

The incremental dimensioning system has an initial reference point for each axis. However that point is only meaningful for movement to the first position. Subsequent moves are in increments from the present work position to the next.

The steps in manual preparation of a N/C machine control tape are shown in Figure 4. The process begins with an engineering drawing of the part. This drawing provides information needed to prepare a part program manuscript. The manually prepared manuscript, including tooling considerations, is then used to prepare a perforated tape. After a tryout, this perforated machine control tape goes to the manufacturing area for use in production.

Summary

The related information presented illustrates that N/C part programming can indeed be a vehicle for teaching and applying several basic drafting principles. Furthermore, part programming provides a meaningful and contemporary justification for learning to dimension using the absolute and incremental techniques. This is but one example of the many ways students can be acquainted with the principles of N/C in established industrial arts programs without expensive new equipment.

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MANUAL PREPARATION OF AN N/C MACHINE CONTROL TAPE

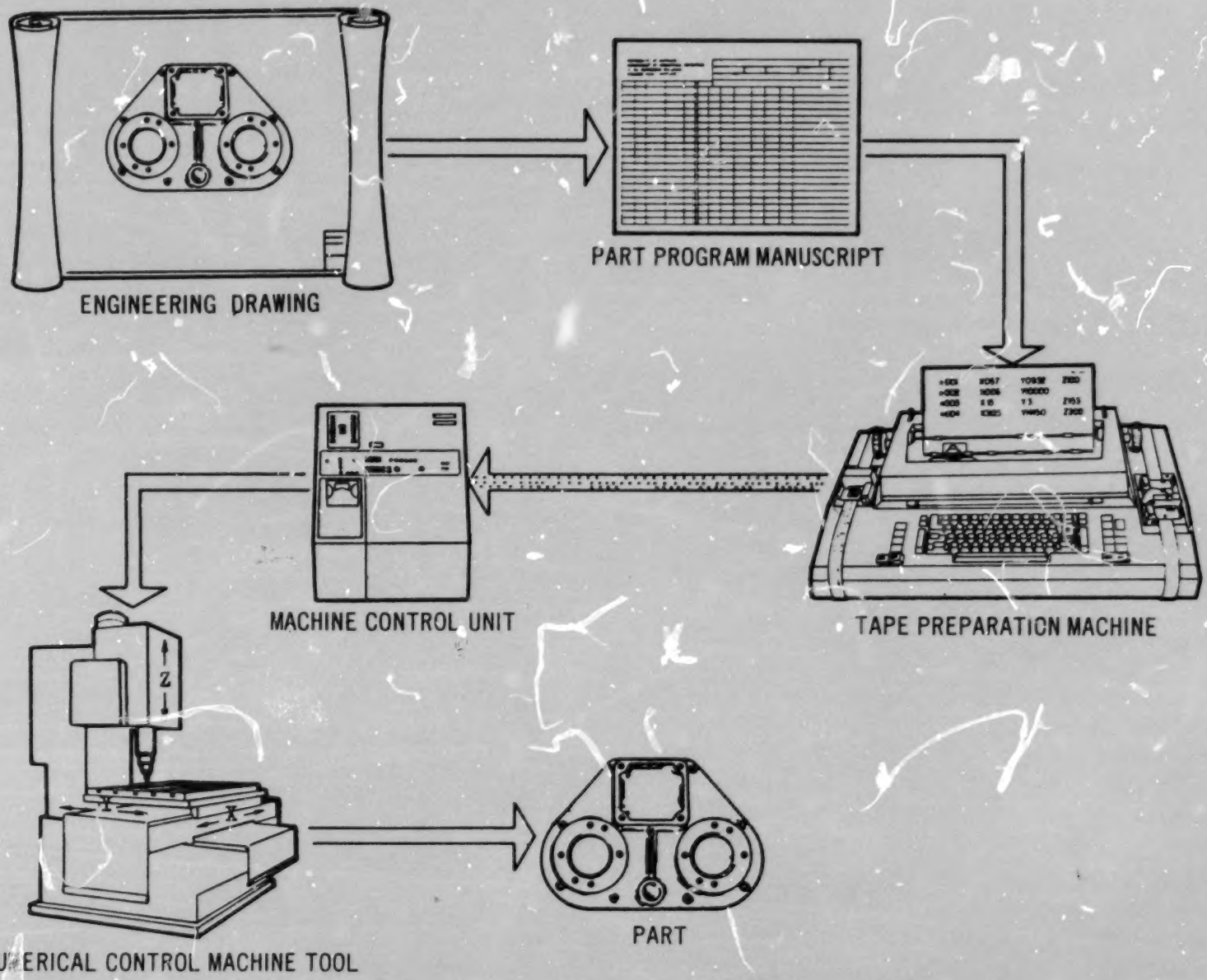


FIGURE 4

An awareness of N/C's implications in manufacturing could be gained through films available from most machine tool builders. Selected films followed up by knowledgeable guest speakers from industry and field trips to manufacturing plants, as well as computer centers, provide familiarization with the equipment, facilities and applications of N/C technology.

A cooperative effort with industry could mature into an educational partnership to acquaint students with the principles and applications of N/C technology. For some, such a partnership could lead to meaningful and rewarding career opportunities in N/C technology.

SECTION II

TAB SEQUENTIAL EXERCISES

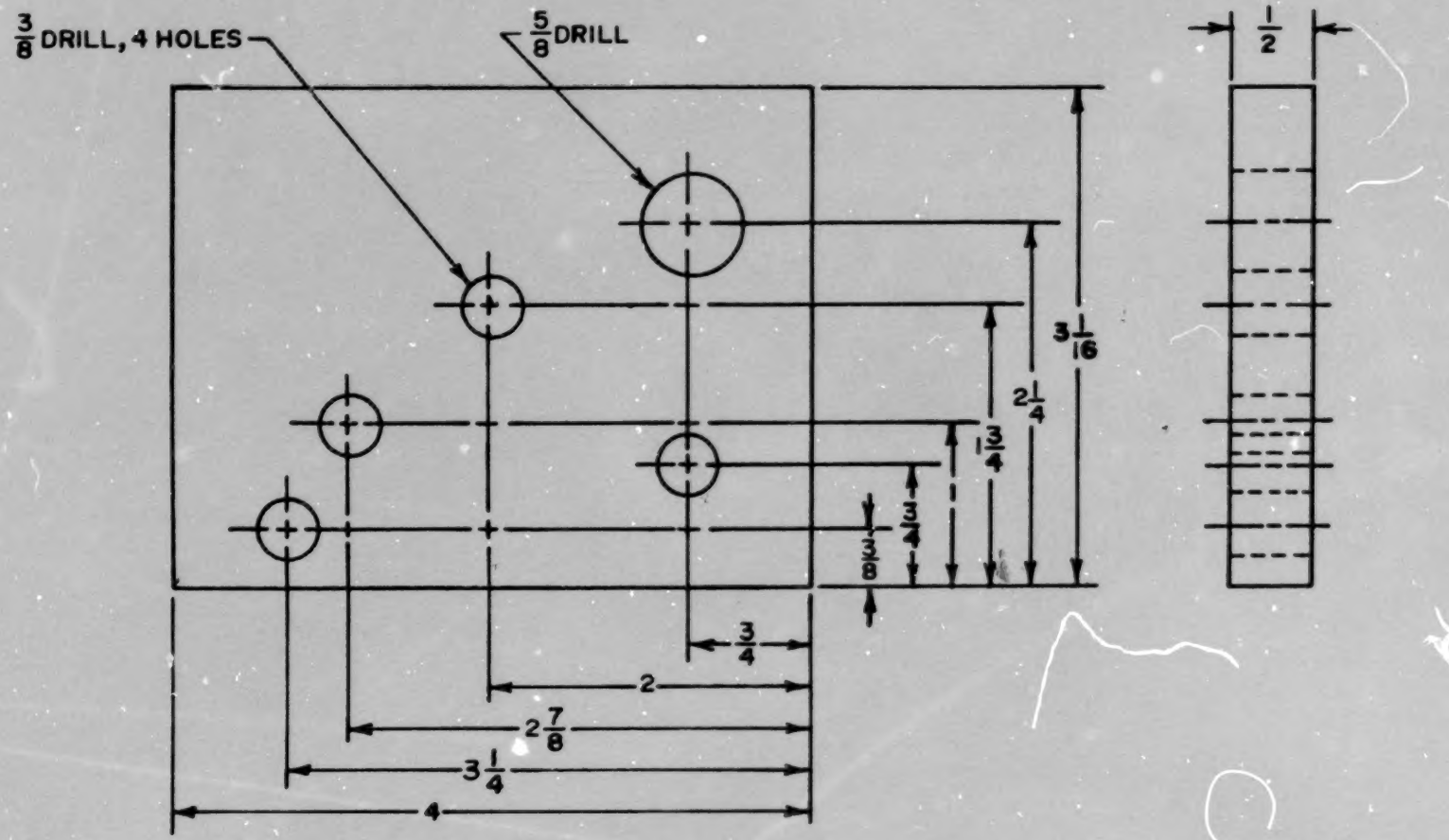
This is a combination introduction to Numerical Control and workbook. It includes practical problems in N/C part programming.

Complete a tab sequential part program for each of the parts listed below, performing the operations indicated.

Part Number 100 - - - - - - Drill

Part Number 110 - - - - - - Drill and Bore

Part Number 120 - - - - - - Drill and Tap



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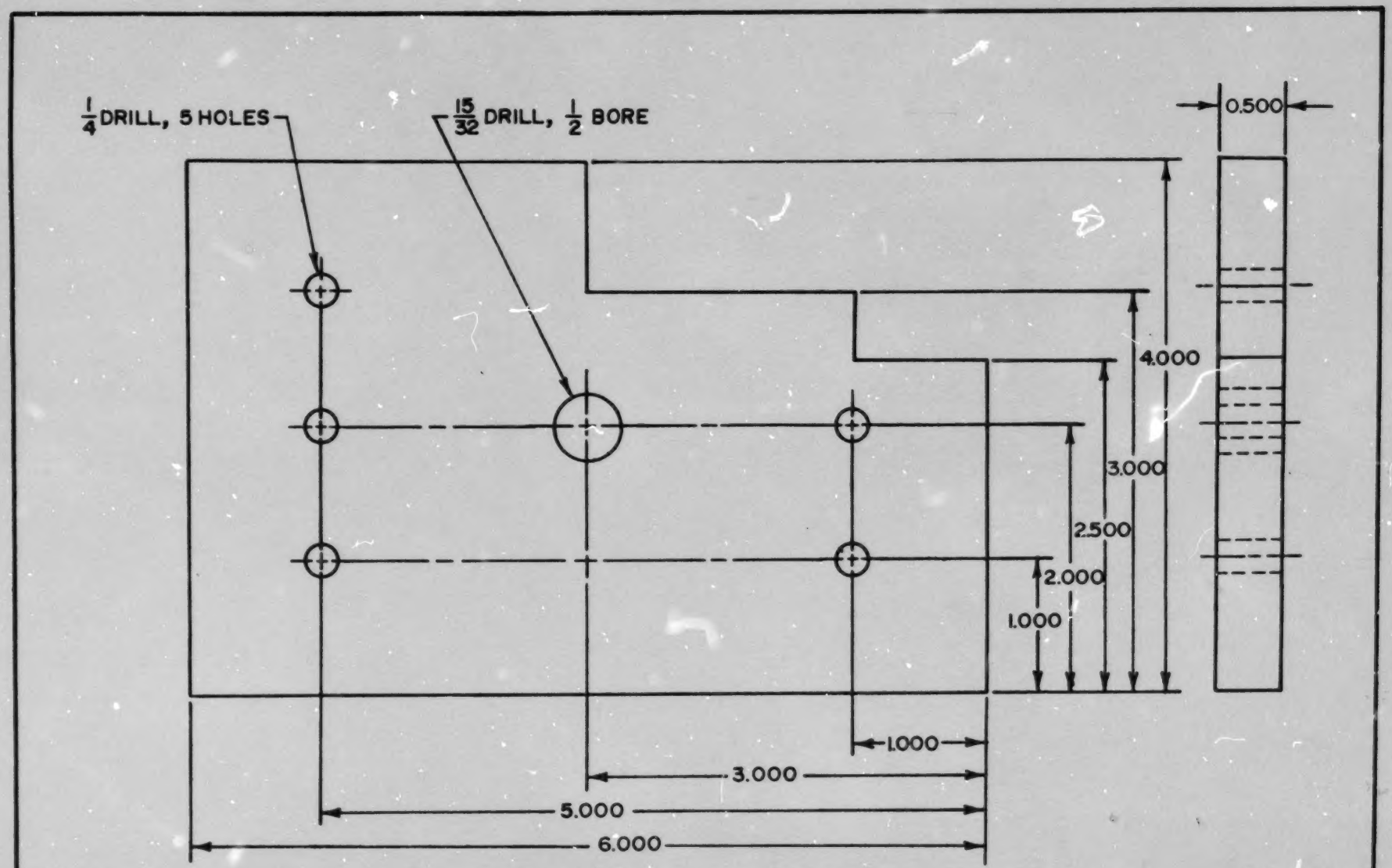

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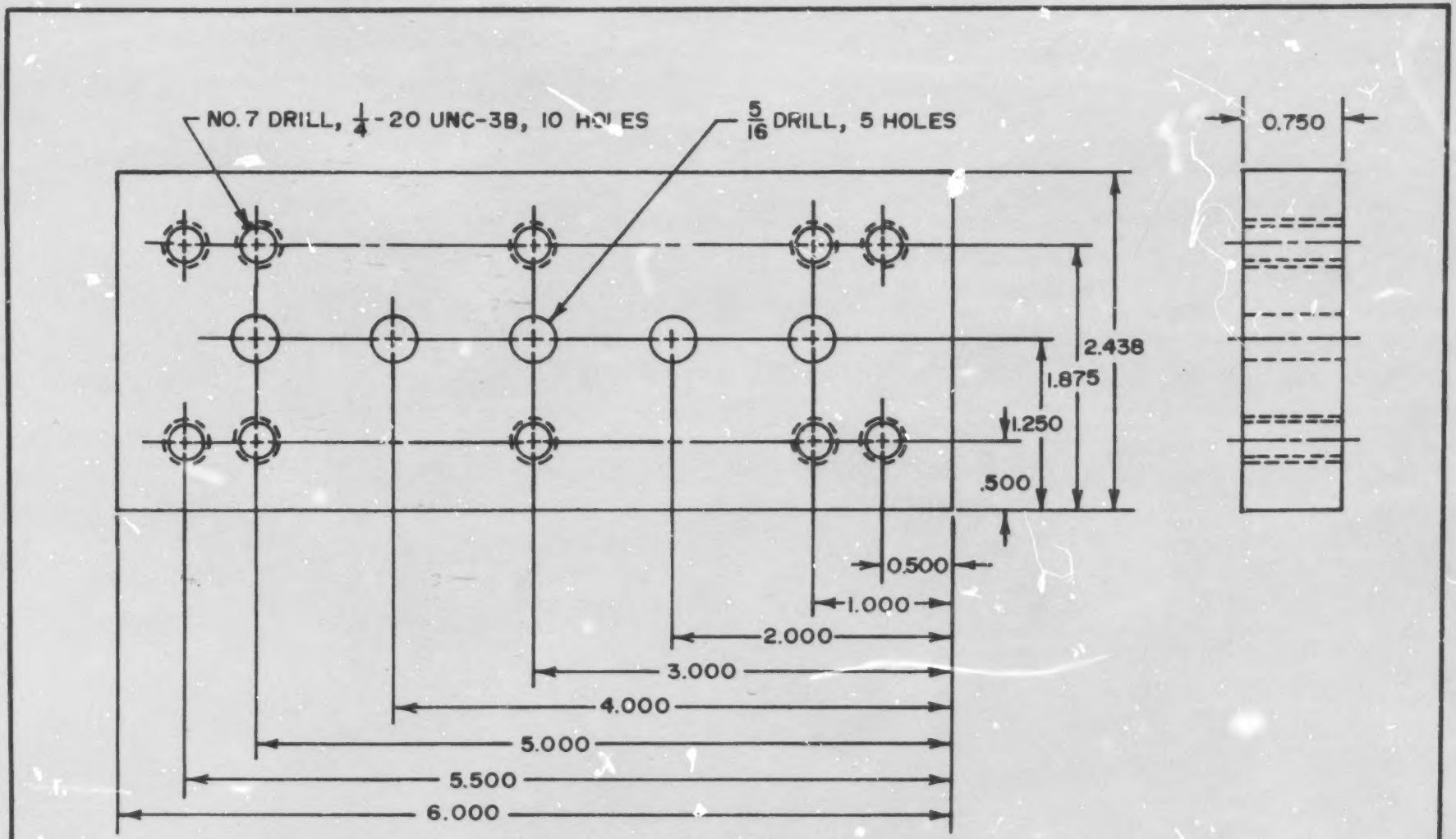

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SECTION III

VARIABLE BLOCK EXERCISES

This is a combination introduction to Numerical Control and workbook. It includes practical problems in N/C part programming.

Complete a variable block part program for each of the parts listed below, performing the operations indicated.

Part Number 200 - - - - - - - Drill

Part Number 210 - - - - - - - Drill and Bore

Part Number 220 - - - - - - - Drill, Bore and Tap

Part Number 230 - - - - - - - Drill, Tap and Light Mill

Part Number 240 - - - - - - - Drill, Bore, Tap and Heavy Mill

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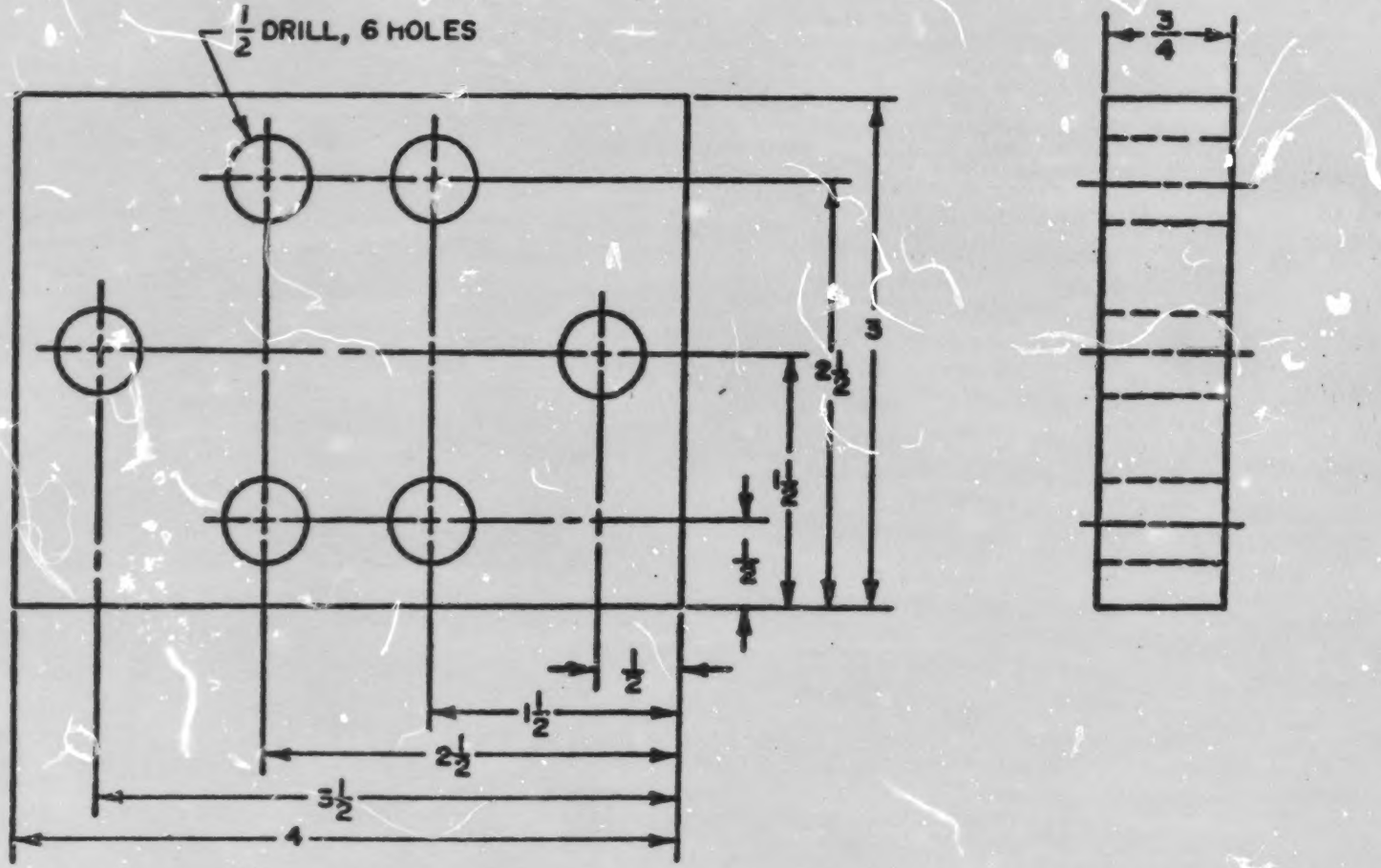

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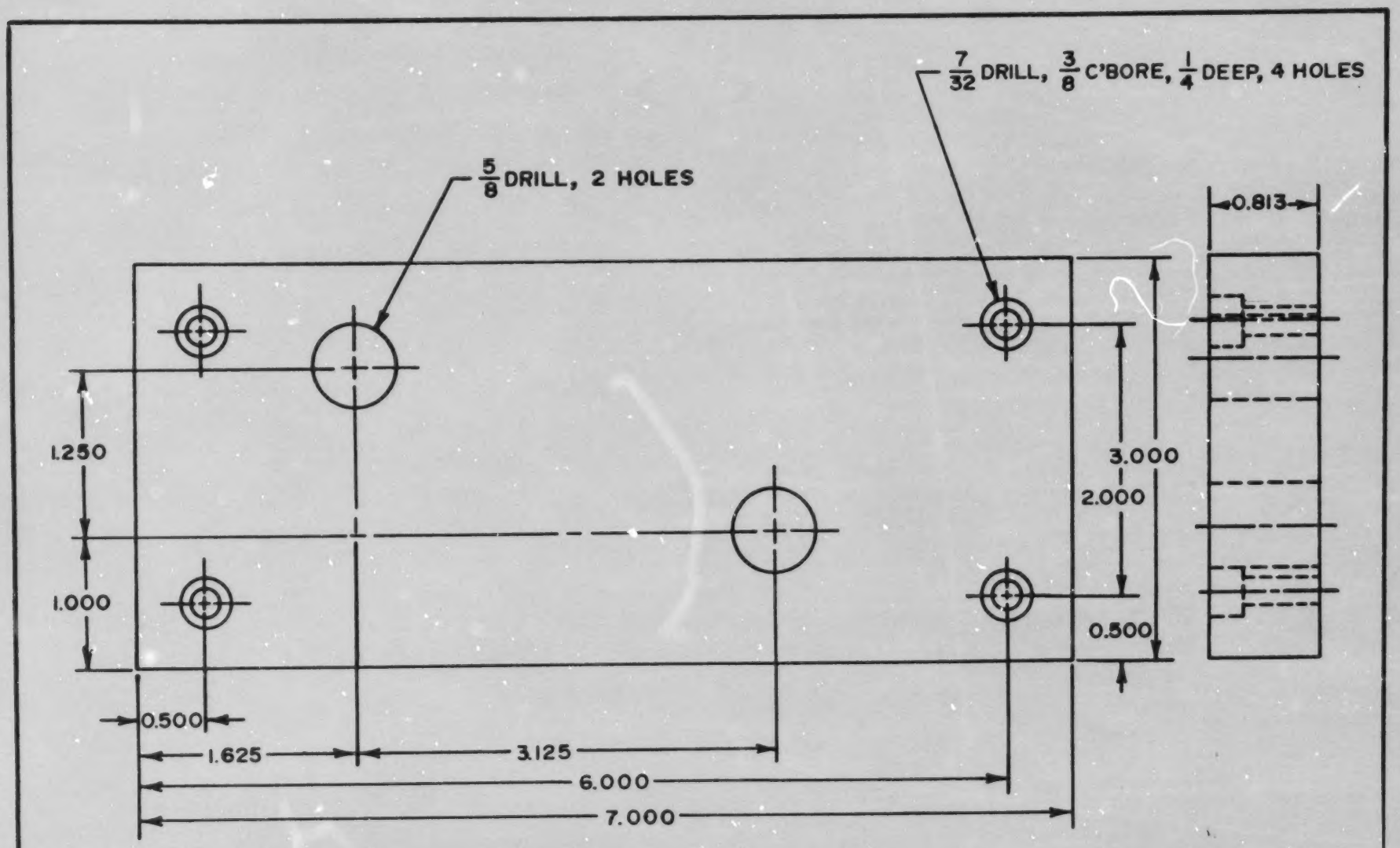

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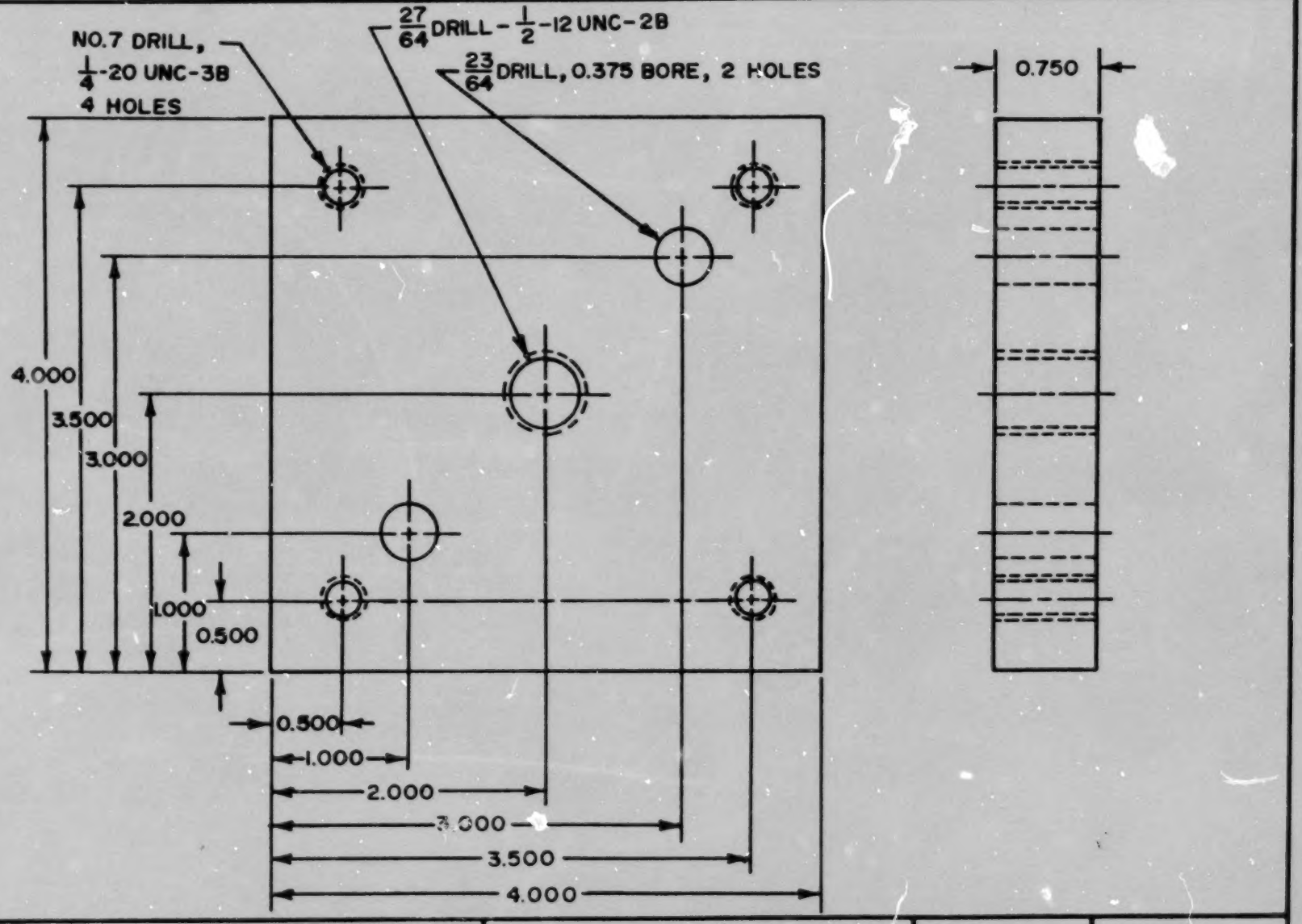

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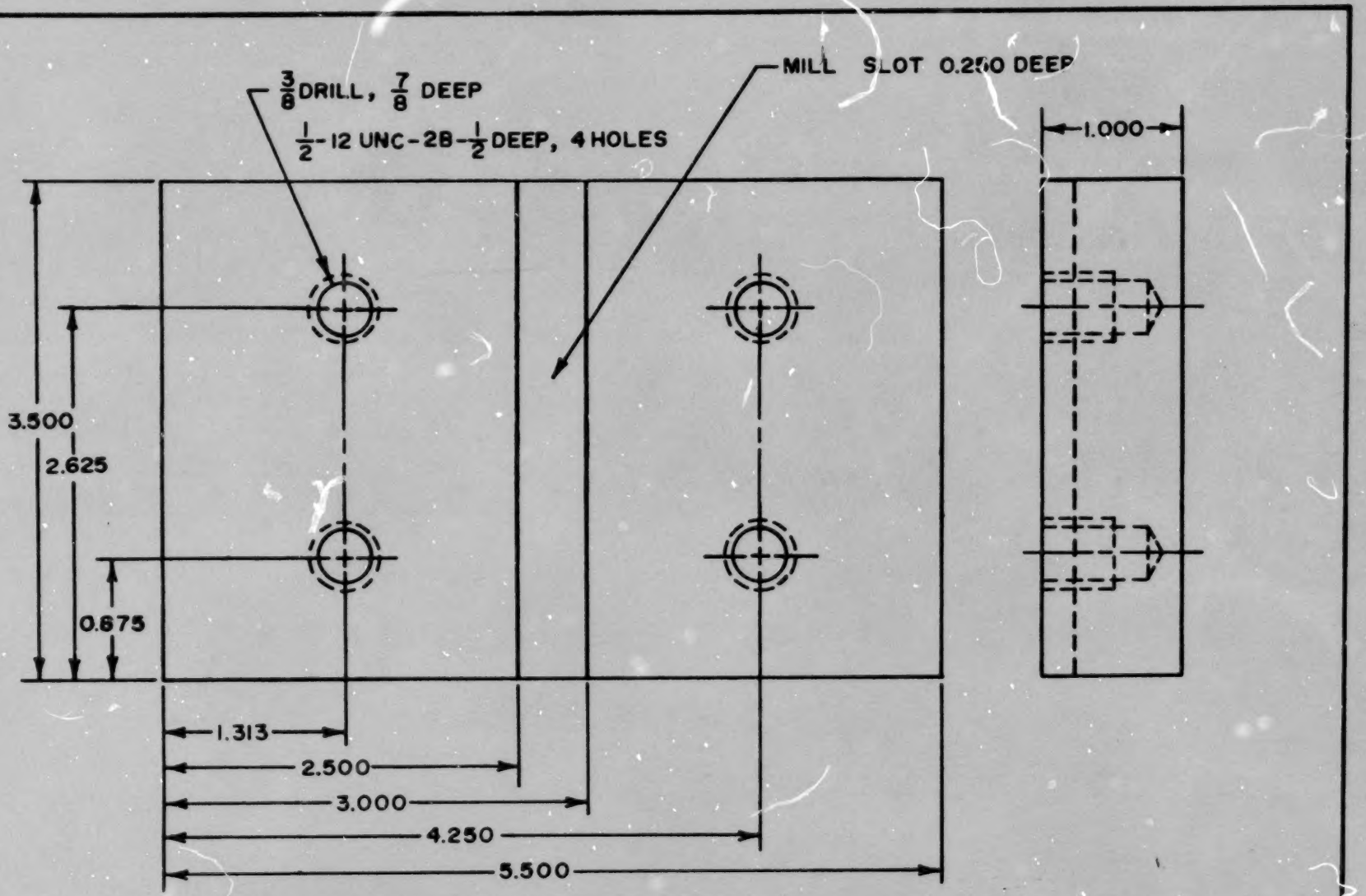

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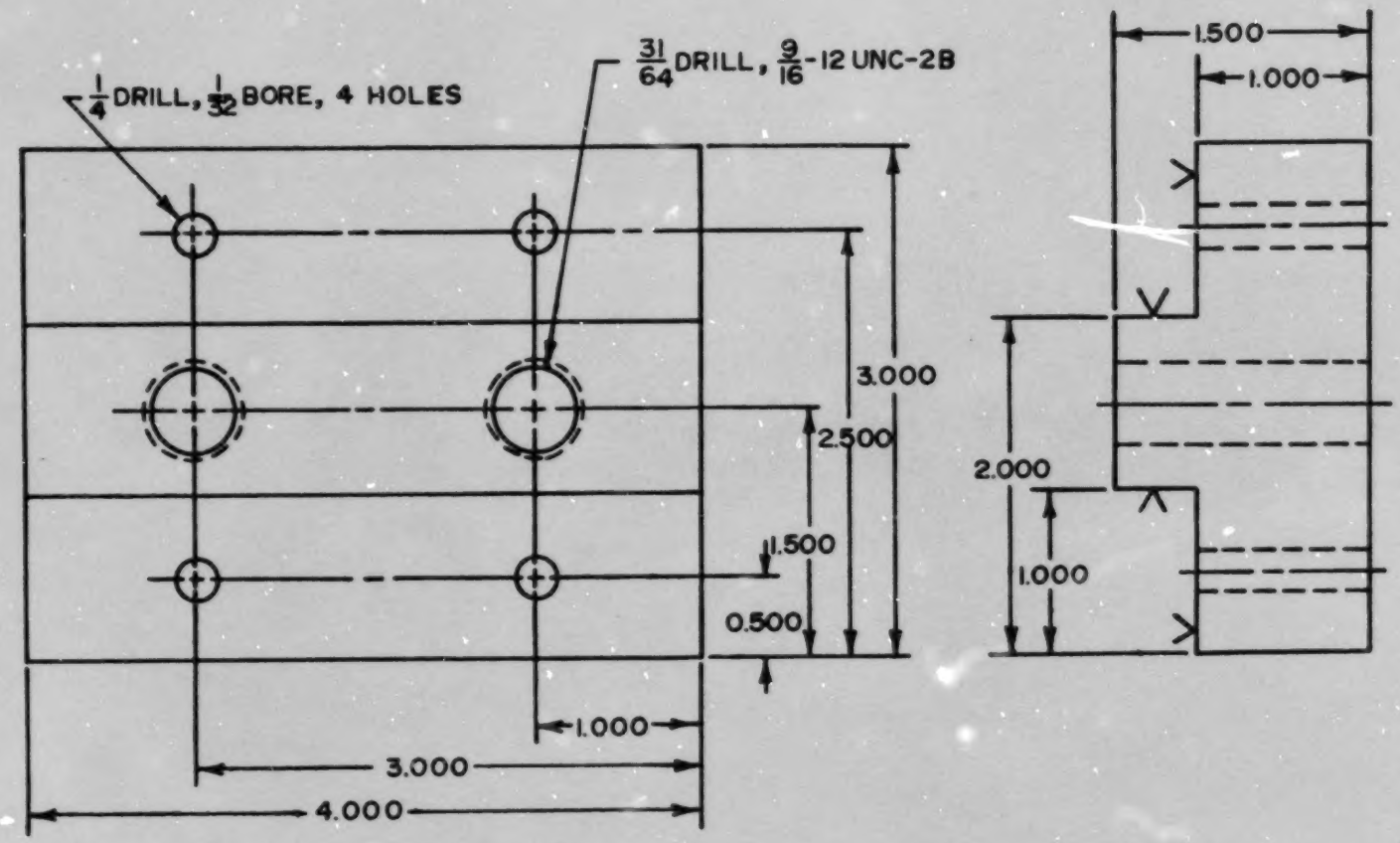

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SECTION IV

FIXED BLOCK EXERCISES

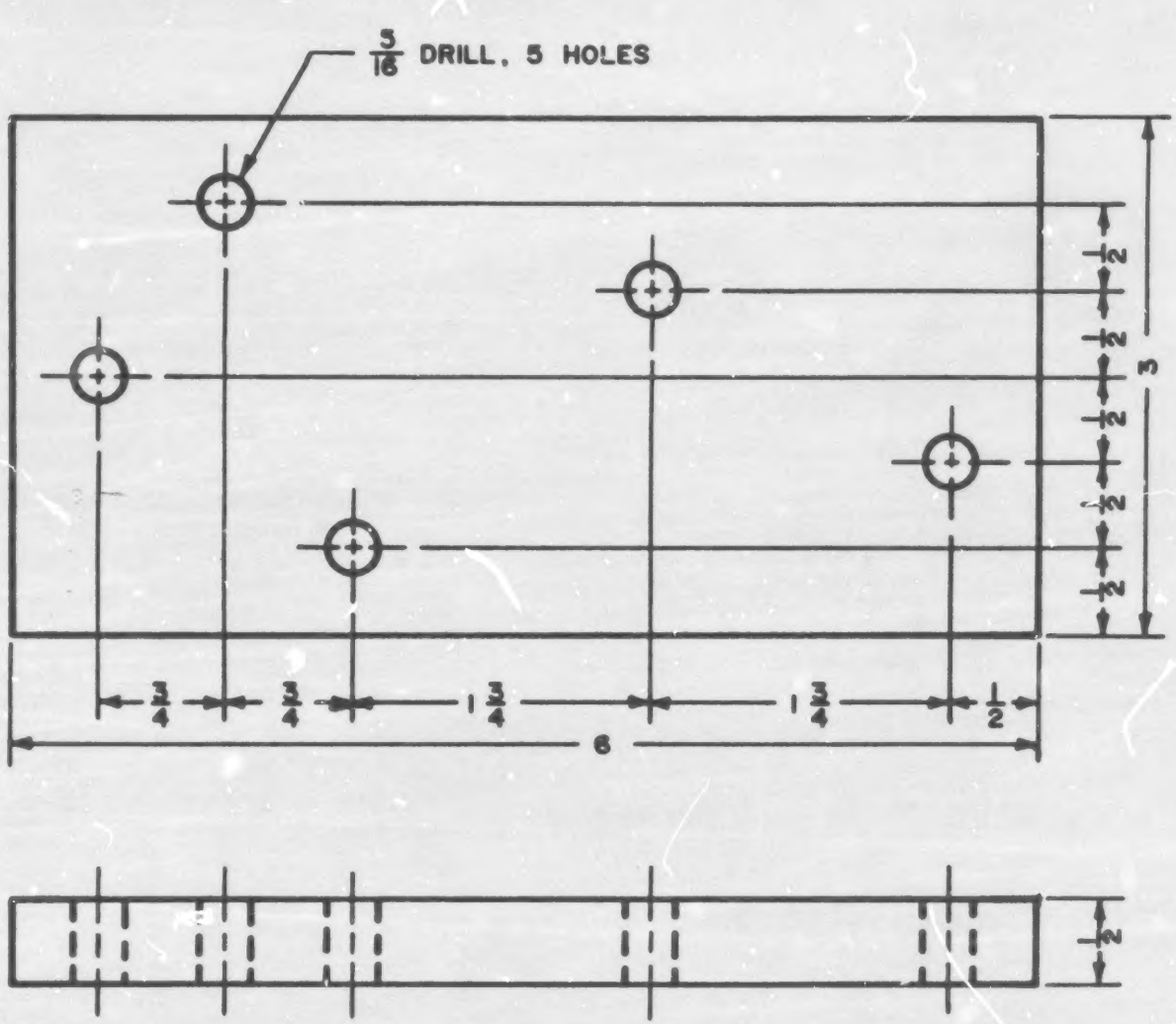
This is a combination introduction to Numerical Control and workbook. It includes practical problems in N/C part programming.

Complete a fixed block part program for each of the parts listed below, performing the operations indicated.

Part Number 300 - - - - - - Drill

Part Number 310 - - - - - - Drill

Part Number 320 - - - - - - Drill and Light Mill



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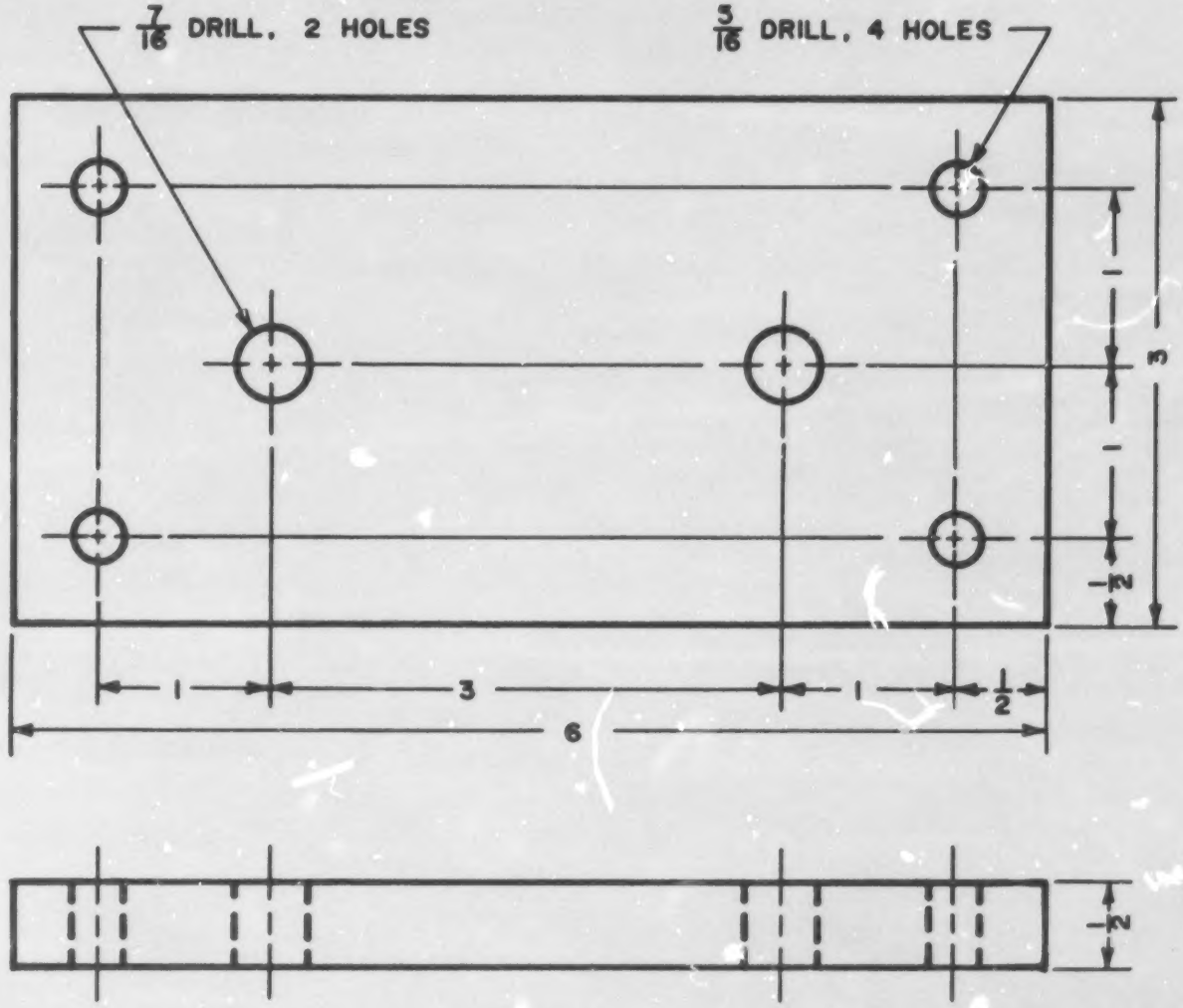

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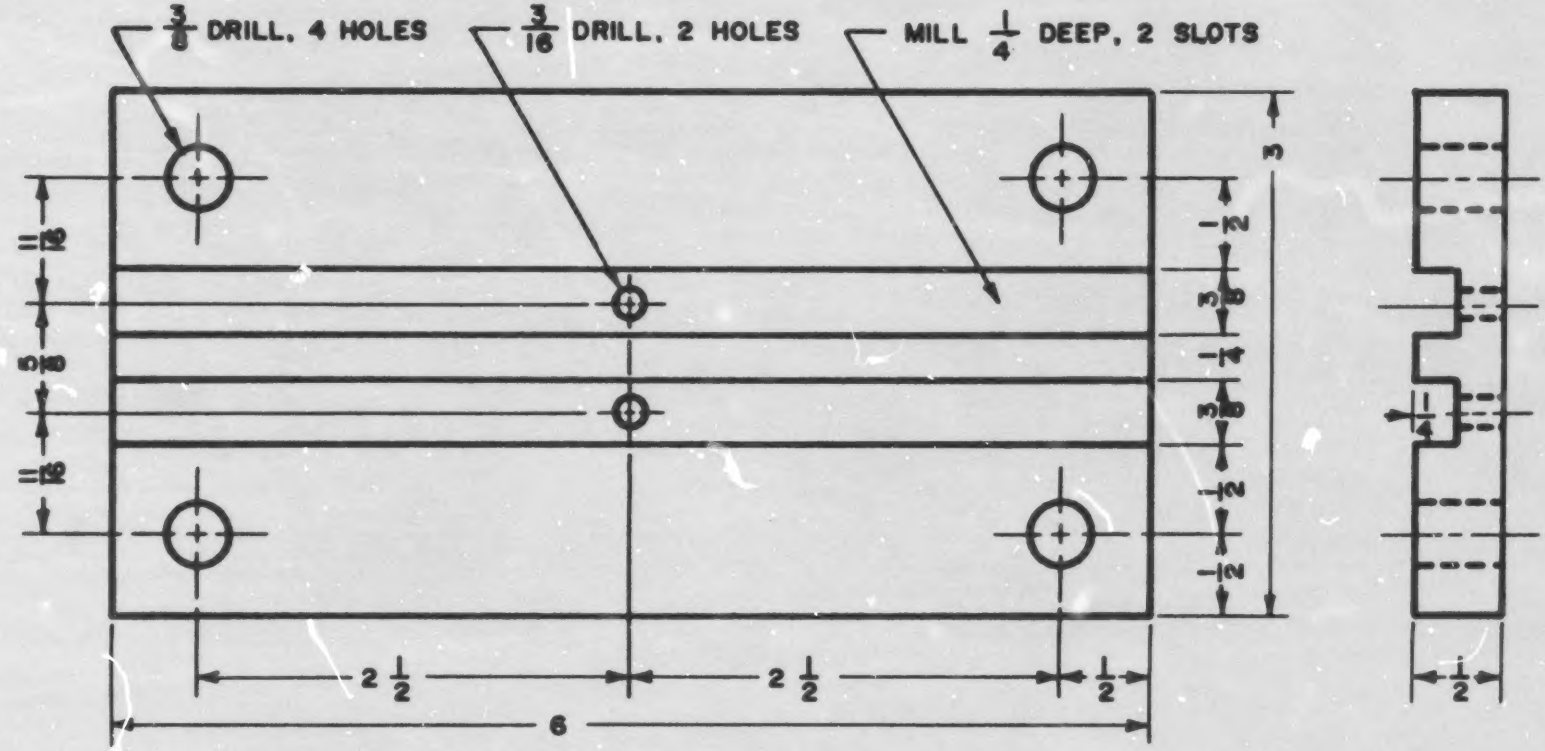

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SECTION V

NUMERICAL CONTROLLED EQUIPMENT

This section presents a description of numerical control operational devices. It has been said that the scope of N/C applications is limited only by economic feasibility and man's ingenuity. Thus, it can be applied to any operation that requires controlled motion.

The classifications of design and drafting, production equipment, and inspection and testing are used to organize the information provided on N/C operational devices.

Design and Drafting

Numerically controlled drafting and plotting machines have many uses. Among them are: preparation of preliminary design drawings from mathematical descriptions; verification of tool and cutting path data on machine control input media; contour mapping; layout of printed circuit artwork masters and inspection templates; architectural drafting; automatic drafting of complex three-dimensional shapes such as aerodynamic surfaces, automobile bodies, ship hull forms, tire treads, impellers and turbine blades.[1] These machines are also used to prepare graphs, charts and other illustrations.

Numerically Controlled Drafting Machines. A complete computer-aided drafting system consists of a digital computer and N/C drafting machine. Drafting machines are connected directly to a computer or are off-line and use computer output as a control media. The off-line mode of operation is normally used because of the time disparity between the electronic speed of the computer and the mechanical speed of the drafting machine.

Mathematical descriptions in numerical form are prepared by a part programmer and processed through a computer, resulting in coordinate data encoded

on magnetic tape, punched cards or punched tape. This output constitutes a set of detailed instructions which are used by the N/C drafting machine to produce a graphical presentation.[2] Input media is fed through the reading device of an N/C drafting machine and processed by the control unit. Control output signals drive a pen, stylus or optical exposure head on the drafting machine to produce an accurate, quality drawing on various materials, at speeds greater than those obtainable manually. All types of lines and forms can be drawn in a number of widths and colors. The N/C drafting machine can provide mirror image or reverse drawings, scale up or down, rotate, translate and project data to any desired view.[3] Some models have (a) full alphabetic and numeric printing capabilities, and (b) digitizing capabilities for the acquisition of coordinate data to define points, lines and curves on existing drawings or patterns.

A representative example of an N/C drafting machne is pictured in Figure 1. The Series 600 control unit and Model 22 graphic display table are manufactured by the Gerber Scientific Instrument Company. This is a solid state continuous path system with buffer storage, a sequence number display and a linear interpolator. It can draw at the rate of 150 inches per minute with accuracy of $\pm$0.007 inch and can scale the size of a graphic presentation from half size to 16 times size.[4] A drawing head, with an optical turret for automatic selection from six different drawing tools, is positioned by an X and Y carriage which executes the commands of the control unit. Positioning along the X axis is achieved by a rack and pinion gear train adjacent to the precision table ways. The Y carriage basic tool holder is positioned along the X carriage by a helical lead screw. Digital stepping motors are used in the basic drive system of both axes.

Numerically Controlled Plotting Machines. Plotting machines are similar in concept and operation to N/C drafting machines. The differences are usually in

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the degree of accuracy and the quality of the graphical presentation that can be produced. The plotter is an X-Y positioning system which can plot computer output as it is being generated or operate off-line using computer output as a control media. When the plotter is used on-line, the plot data and control commands are supplied through interface electronics. In the off-line mode of operation, which is normally used, magnetic tape is played back on the control unit which supplies the X and Y axis drive signals, mode selection signals and Z axis commands to the plotter.[5] Many N/C plotters have mirror image capability and drawing scale flexibility. They are available in flatbed and drum models.

A representative example of an N/C plotting machine is illustrated in Figure 2. The Calcomp Model 565 drum plotter is manufactured by California Computer Products, Incorporated. It has an X-Y axis plotting speed of 18,000 steps per minute and a Z axis (pen) speed of 600 operations per minute. Bidirectional stepping motors are used to position the X and Y axes. Plotting is regulated by the movements of a pen relative to the surface of the paper, with each input pulse causing a step of either 0.01 or 0.005 inch. The X axis deflection is produced by the motion of a rotating drum, and the Y axis deflection is produced by the motion of a pen carriage. Command signals raise and lower the liquid ink or ballpoint pen from the surface of the paper. All plotting, discrete points, continuous lines or symbols are accomplished by the stepping action of the drum and pen carriage. Paper alignment is maintained by sprockets on the drum. Various types of roll stock paper and mylar are used. Manual controls for positioning the drum and pen carriage and for raising and lowering the pen are provided. Controls to initiate any of three modes of operation (search, single plot and multiple plot) in addition to miscellaneous tape modes such as fast forward and rewind are located on the front panel of the control unit.[6]

Production Equipment

Numerical control has been adopted more extensively for production equipment than by any other application. General acceptance came about as a result of its inherent qualities of increased accuracy, increased production and interchangeability of the end product.[7]

Drilling Machines. A large number and variety of N/C drilling machines are marketed. The key advantage of N/C drilling is the elimination of costs associated with positioning jigs and fixtures.[8] Numerically controlled drilling machines are available in a variety of models, from two-axis machines with single spindles to three-axis machines with automatic tool changers or turrets. Many of the drilling machines have some milling capability.

Typical of the smaller types of special purpose N/C drilling machines are printed circuit board drills. These machines are equipped with single or multiple stations. A drilling machine designed for precision drilling of a large number of holes in printed circuit boards or other flat stock is illustrated in Figure 3. This machine, manfactured by the Edlund Division of the Monarch Machine Tool Company, has four stations, each with a cluster of four drill spindles with independent feed and speed control. The positioning table is mounted on the base along with a column which holds a vertically adjusted bracket fitted with independent air feed units of four groups of four units each. The drills are automatically selected by programmed information and the positioning speed is 200 inches per minute.[9]

A typical general purpose two-axis N/C drilling machine is the Moog Model 83-200. This representative example of a point-to-point vertical drilling machine capable of limited straight line milling along the X and Y axes is pictured in Figure 4. It has a single spindle with manual or mechanical Z axis control and

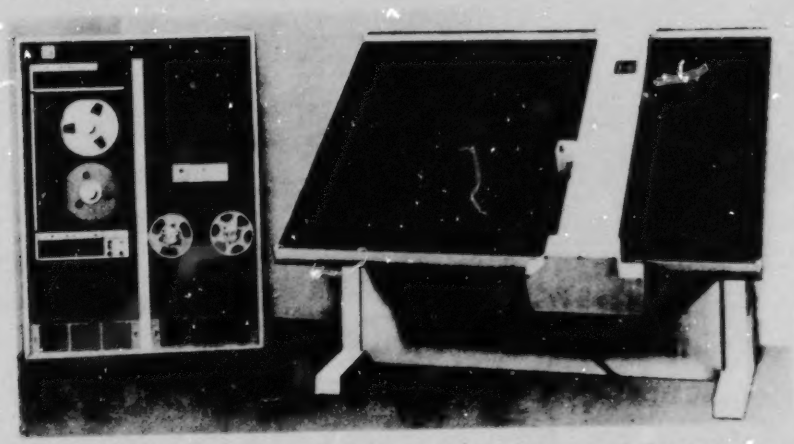

Figure 1. Drafting Machine. (Courtesy of Gerber Scientific Instrument Company)

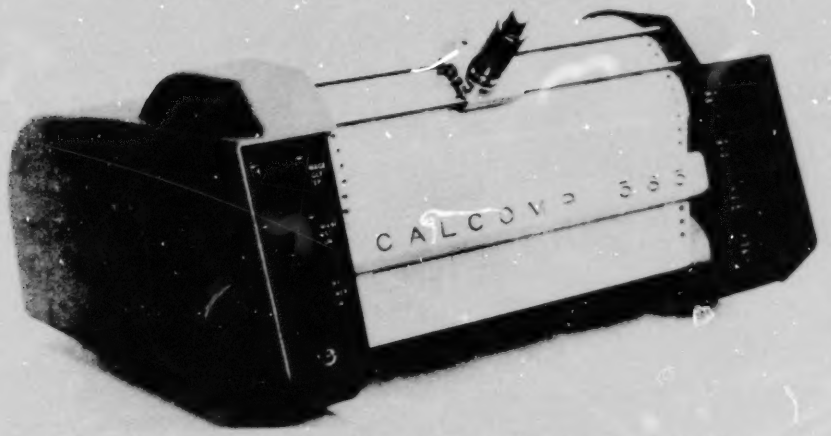

Figure 2. Plotting Machine. (Courtesy of California Computer Products, Inc.)

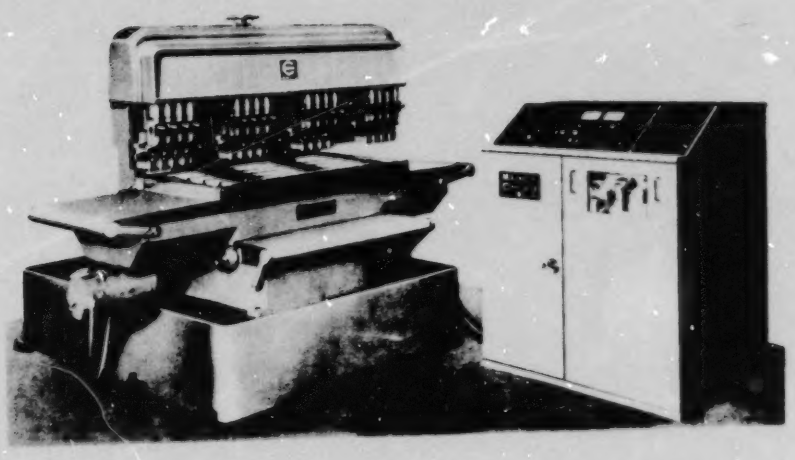

Figure 3. Printed circuit board drill. (Courtesy of Edlund Division of Monarch Machine Tool Company)

manual tool changing. The pneumatic-hydraulic positioning control system positions at the rate of 180 to 200 inches per minute with ±0.001 inch accuracy. Control and positioning components used in this machine are manufactured by Moog, Incorporated and are fitted at the factory to a specially designed and built Bridgeport vertical mill.[10] The machine control unit (MCU) attached to the head of the machine tool contains a pneumatic block reading device, manual input dials and a mechanical sequence counter.

Another successful application of N/C drilling is turret drilling. The turret head functions to some degree as an automatic tool changer. The number of tools used (six, eight to ten) varies with the design of the turret. Numerically controlled turret drills are capable of cycling automatically, selecting tools and positioning the table and carriage in the X and Y direction. Both two- and three-axis control systems are used. A typical N/C turret drill is illustrated in Figure 5. This Burgmaster Model 3 BHT-3, manufactured by the Burgmaster Division of Houdaille Industries, has double housing planer type construction which provides maximum strength and precision for large workpieces. The machine tool has an eight spindle turret and is equipped with a General Electric Mark Century MCU. It has a three-axis positioning control and can perform milling and boring operations in addition to drilling.[11]

Milling Machines. There are various kinds of milling machines, such as die sinkers, contouring and profiling machines, skin and spar mills, as well as general purpose knee and bed models. Milling machines are generally classified as horizontal or vertical type.[12]

A representative N/C horizontal milling machine is pictured in Figure 6. This two-axis Cincinnati milling machine, with an Acramatic 220 solid state point-to-point MCU, is manufactured by the Cincinnati Milacron Company. The

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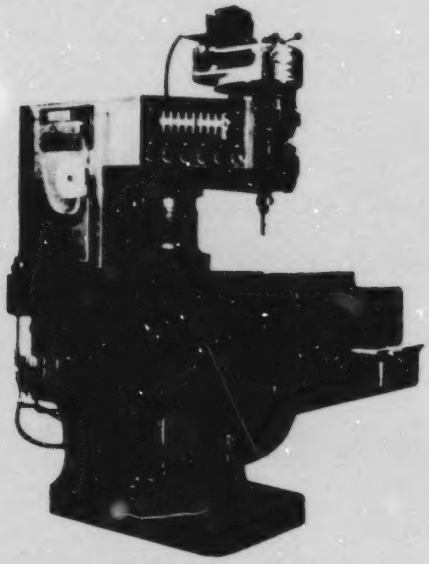

Figure 4. Two-axis drilling machine.
(Courtesy of Moog, Incorporated)

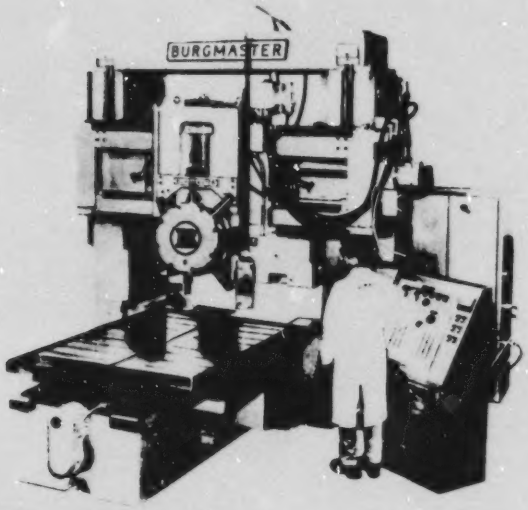

Figure 5. Turret drill. (Courtesy of
Burgmaster Division of Houdaille
Industries)

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MCU is equipped with a tape reading device, manual input decade switches, and sequence number and position displays. In addition, it has full range zero shift capability. A 33 1/4 by 48 inch work table handles workpieces as heavy as 5,500 pounds at milling feedrates of two to thirty inches per minute. The table is positioned by a 7 1/2 horsepower hydraulic servo motor driving a ball nut lead screw. Third axis (Z) control is facilitated through manually set cams. This N/C machine tool is capable of drilling, tapping, boring and milling operations.[13]

A two-axis Cincinnati vertical N/C milling machine with an Acramatic 220 point-to-point MCU is illustrated in Figure 7. The machine control unit and other components are identical to those used in the horizontal milling machine described above. A 20 by 40 inch work table which handles workpieces as heavy as 1,500 pounds is positioned by a five horsepower hydraulic servo motor. In addition to miling, operations such as drilling, tapping and boring can be performed on this machine.

Boring Machines. Numerically controlled boring machines, with two to eight axes of movement, have been equipped with point-to-point or continuous path control systems. They are classified as horizontal or vertical machines.[14]

In horizontal boring, a horizontal spindle and cutting tool remove metal by rotation of the spindle. The workpiece is located on a table which can position in the X and Y directions and in some cases a rotary table is used for 360 degree positioning. This type of machine can be used to bore, mill and drill. A horizontal boring machine, manufactured by the Lucas Machine Division of The New Britain Machine Company, is shown in Figure 8. The Lucas Model 542B120 is equipped with a three-axis continuous path machine control unit. A rotary transducer is mounted directly on the end of the lead screw, which is driven by a hydraulic motor and servovalve.[15]

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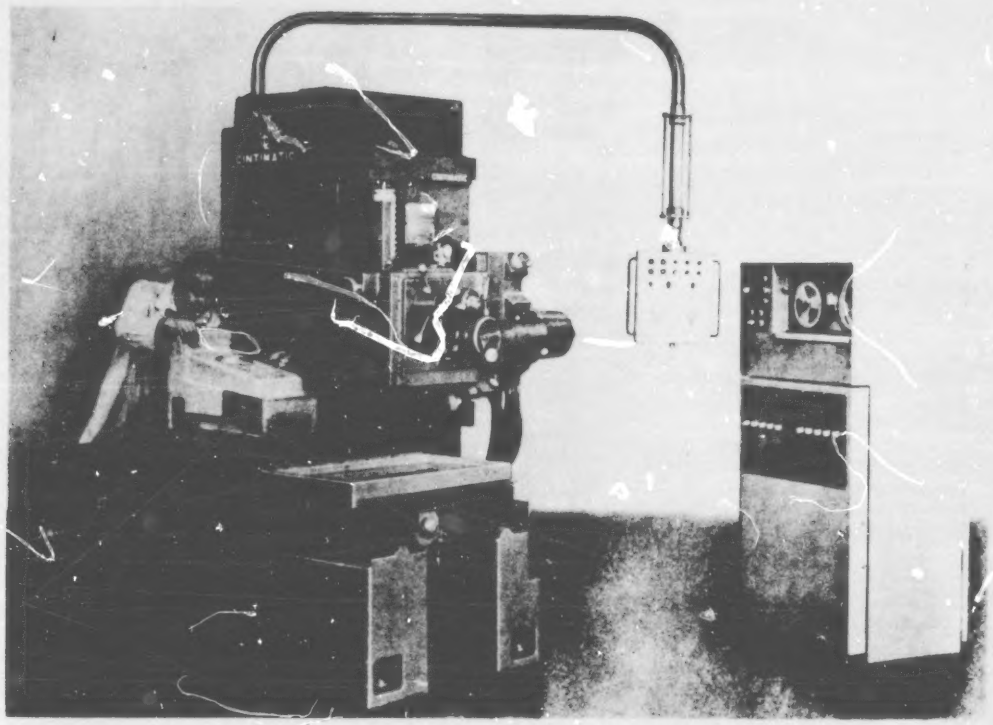

Figure 6. Horizontal milling machine. (Courtesy of Cincinnati Milacron Company)

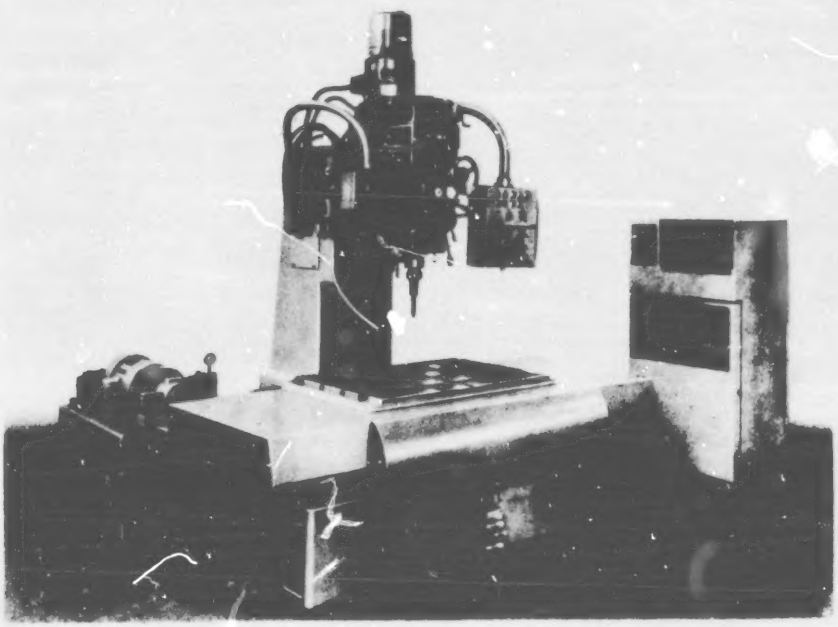

Figure 7. Vertical milling machine. (Courtesy of Cincinnati Milacron Company)

A vertical boring machine consists of a large rotating table to which a workpiece is attached. An adjustable rail containing the cross rail head (or heads) is mounted on columns. The head(s) move in or out on the rail. In addition to boring, this machine can perform turning and other operations similar to those done by vertical turret lathes. A single head vertical boring machine, manufactured by the G.A. Gray Company, is illustrated in Figure 9. This machine has an integrated circuit two-axis continuous path MCU with linear and circular interpolation.[16] Commands from the MCU determine the speed of a rotating table driven by helical and spiral bevel gears powered by a DC motor. A five tool indexing turret attached to the end of a ram can be extended into deep holes.

Turning Machines. Some of the different types of N/C turning machines or lathes are the (a) horizontal turret lathe, (b) vertical turret lathe, (c) engine lathe and (d) chucking lathe. The horizontal turret lathe (bar lathe) is generally used for multiple cuts such as drilling, boring, reaming, tapping, facing, turning and parting off detail parts from random length metal bars. A representative N/C horizontal turret lathe is pictured in Figure 10. This is a Jones and Lamson Model 4518-NCTL three-axis turret lathe with a General Electric Mark Century MCU, manufactured by Jones and Lamson Division of Waterbury Farrel Company. The MCU facilitates manual data input and manual operation, as well as tape control for turning. The turret lathe carriage and cross slide respond to linear and circular interpolation of programmed information for continuous path turning. At the same time, the saddle responds to end point positions for the third axis of motion. Each slide is positioned by an electric or hydraulic motor driving a ball nut lead screw. A rotary resolver, driven by the lead screw, provides feedback to the closed loop system.[17]

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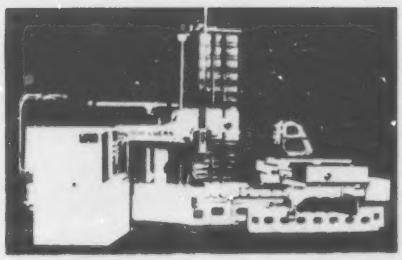

Figure 8. Horizontal boring machine. (Courtesy of Lucas Machine Division of The New Britain Machine Company)

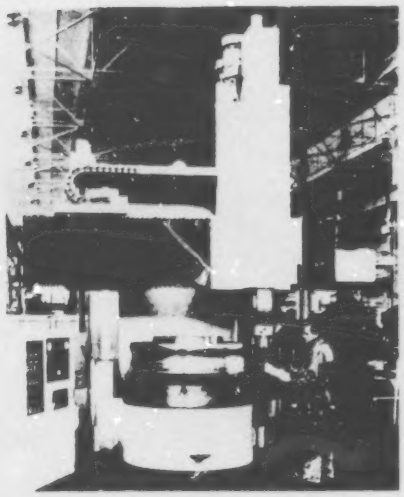

Figure 9. Vertical boring machine. (Courtesy of G. A. Gray Company)

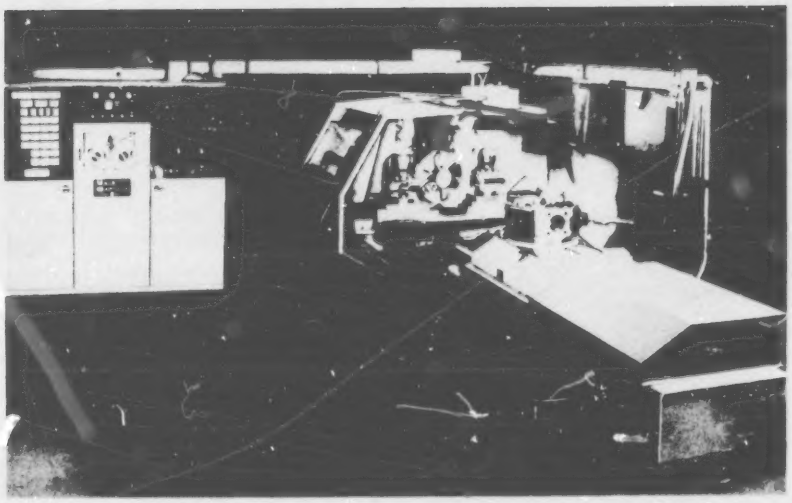

Figure 10. Horizontal turret lathe. (Courtesy of Jones and Lamson, Division of Waterbury Farrel--A Textron Company)

The vertical turret lathe is used for multiple cuts such as facing, turning and/or boring of parts too large to be machined on standard-size horizontal lathes. A vertical Giddings and Lewis turret lathe is illustrated in Figure 11. It is equipped with a four-axis N/C point-to-point control system. Two of the four axes control the ram head while the other two control the side head. Commands from the MCU index the turret and determine table speeds. The work table is driven by a variable speed DC motor with a high and low gear. When equipped with a continuous path control system, this machine uses an Inductosyn linear feedback device for each axis under control of the MCU.

The engine lathe is customarily used for turning parts between centers of for facing, turning, boring or single point thread chasing on workpieces that can be held in a chuck or collet. A representative N/C engine lathe is pictured in Figure 12. This is an American Model 3220 two-axis N/C engine lathe with a General Electric continuous path MCU. It is equipped with resolvers for shifting the zero reference of each axis. An operator's control station mounted on wheels facilitates locating the push-button controls near the carriage of the lathe or in any other convenient place. DC motors operating from silicon-controlled rectifiers drive ball nut lead screws for feed control.[18]

The N/C chucking lathe is used for turning, threading, facing, drilling, boring, reaming and other operations. A representative example of an N/C chucking lathe is the Monarch Pathfinder, manufactured by the Monarch Tool Company. It is equipped with a General Electric Mark Century solid state 1005 machine control unit. The chucking lathe has a hexagonal turret and two tape-actuated auxiliary slides. Two-axis continuous path control of the turret with circular interpolation provides the capacity for generating almost any part configuration within the size limitations of the machine.[19]

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Machining Centers. Thus far in the description of N/C production equipment, drilling, milling, boring and turning machines have been described. Some models of these machines, with automatic tool changers, might fall into the machining center classification. This is the case when they are capable of performing different operations, such as drilling, milling, boring, tapping and reaming. Full automation is one characteristic of a machining center; all system functions are numerically controlled.[20] Optional features of machining centers include multiple spindle heads, shuttle pallet systems, dual tape readers and as many as five axes of machine control.

A representative N/C machining center is shown in Figure 13. This Kearney and Trecker Milwaukee-Matic unit, manufactured by Kearney and Trecker Corporation, is equipped with a point-to-point and continuous path control system which provides positioning and two-axis (X and Y) contouring. It has random tool selection and changing. A pallet shuttle, for the reciprocal machining of a workpiece, automatically transfers a pallet with completed part off the index table and presents another to the machining station.[21] This reduces non-productive time associated with part loading and unloading.

A maximum of 60 preset tools can be loaded at random in a chain type tool storage magazine with one additional in the spindle. The tool storage magazine rotates automatically on command of the MCU and exchanges the preselected tool in the spindle.

Grinding Machines. Grinding is a metalcutting process accomplished by the controlled rotation of an abrasive wheel against a workpiece. Numerical control is applied to grinding because of its ability to control contours and provide close tolerances.[22]

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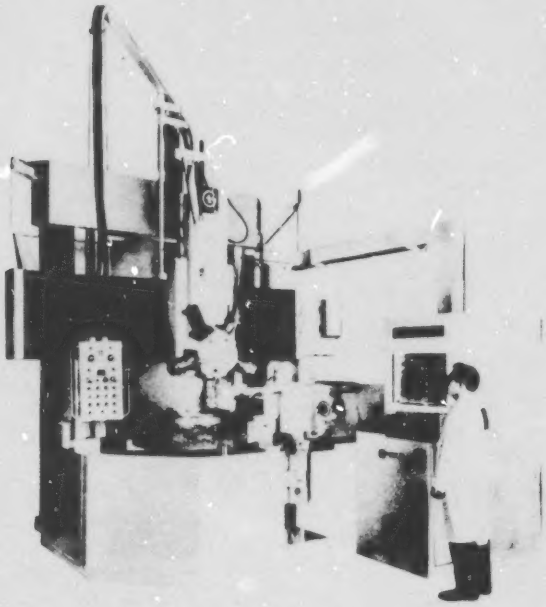

Figure 11. Vertical turret lathe. (Courtesy of Giddings and Lewis Machine Tool Company)

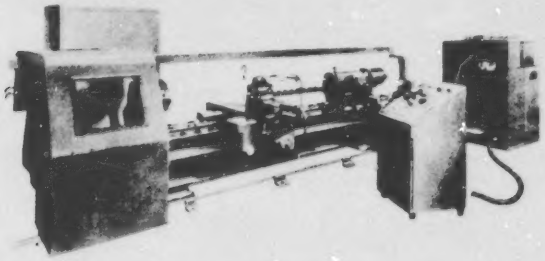

Figure 12. Engine lathe. (Courtesy of The American Tool Works)

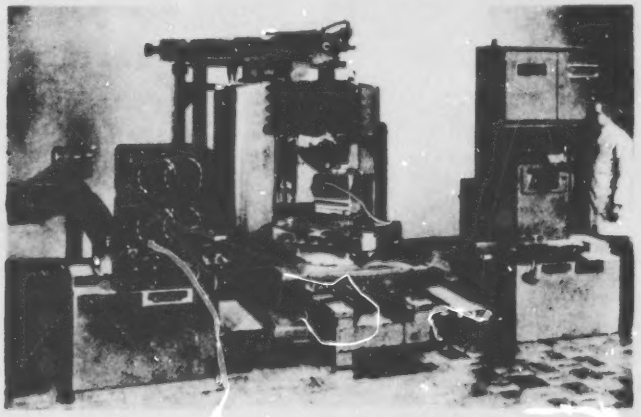

Figure 13. Machining center. (Courtesy of Kearney and Trecker Corporation)

A representative example of an N/C contour grinder is the Numera-Tool, manufactured by the Ex-Cell-O Corporation. This three-axis vertical contour grinder is equipped with a Bendix Dynapath Model 1503 continuous path machine control unit. The integrated circuit MCU is designed to accept computer interface or punched tape input. The machine tool has a 24 inch diameter turntable and a vertical worm gear driven servo controlled spindle. A motorized spindle, mounted to a horizontal servo controlled cross slide and affixed to the vertical servo controlled slide, powers the grinding wheel. Maximum traverse rate in the linear axes is 200 inches per minute, and the maximum rotary speed of the workpiece spindle is 30 revoluations per minute.[23]

Punching and Notching Machines. Punching or piercing produces a hole in sheet or thin plate material. Numerical control makes it possible to select any location, size and shape of hole. Two basic types of N/C presses which provide single stroke piercing have been developed. One is the single station type where tools are manually changed during the cycle, and the other is a turret type which automatically indexes tools into position.[24]

Single station machines hold one punch and die at a time. Numerical control is used to position a workpiece in relation to the punch and die, for punching holes, notching, blanking, nibbling and forming. A representative single station punching and notching machine is pictured in Figure 14. this Strippit Fabramatic Model 30/30 two-axis machine, manufactured by Strippit Division of Houdaille Industries, facilitates short run production of large complex workpieces. Round or shaped holes, notches and cutouts of practically unlimited variety are punched automatically. Although normal operation is automatic, semi-automatic and manual modes are available to verify machine control tapes, check performance or manually operate the machine.[25]

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Turret type punch presses can process a completed workpiece in a single setup. A representative example of a turret type punching and notching machine is illustrated in Figure 15. This two-axis Wiedematic Model A-30 turret punch press, manufactured by the Wiedemann Division of Warner and Swasey Company, is equipped with a General Electric Mark Century point-to-point MCU. Power is provided by rotary hydraulic motors with closed loop servo-valve control and resolver feedback. Both the carriage and cross slide are driven by rack and pinion gears. The 30 station punch turret can be rotated in either direction. All positioning functions, as well as turret indexing, occur simultaneously. In addition to punching round, square or a variety of oval shaped holes, the machine notches, nibbles, pierces and centerpunches.

Tube Bending Machines. Operation of the N/C tube bender consists of positioning a tube, solid bar or heavy wire and then bending it to the desired angle. Improved accuracy, additional versatility and automatic operation, resulting in decreased production costs, inspection time and scrap, are a few of the advantages of N/C bending machines.[26] Tubes bent into a variety of configurations are used by aerospace, aircraft, machine tool, appliance, automotive and other industries. They are particularly useful where relatively few tubes of any one shape are required, although the individual part might have many bends and must match precisely with its mating members.

A representative N/C tube bending machine is illustrated in Figure 16. This Pines Numri-form Model NC-2 N/C tube bending machine and Cynermat integrated circuit MCU are manufactured by the Teledyne Pines Company. The machine control unit is a point-to-point three-axis system. An electronic memory unit in the MCU stores data for as many as 24 bends. Manual and punched tape input are used. Punched tape extends the use to workpieces requiring more than 24 bends

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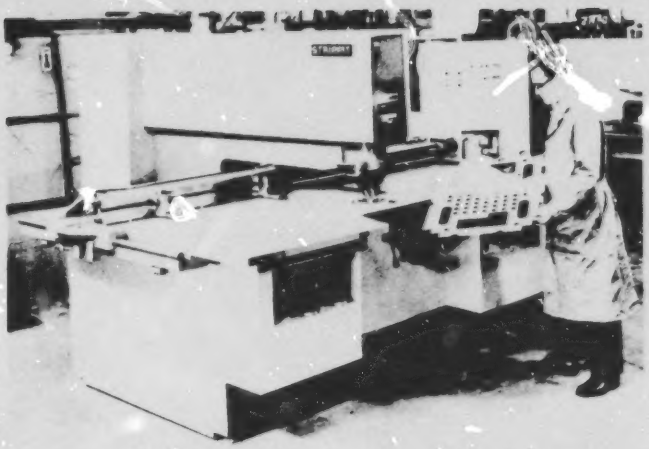

Figure 14. Single station punching and notching machine.
(Courtesy of Strippit, Division of Houdaille Industries)

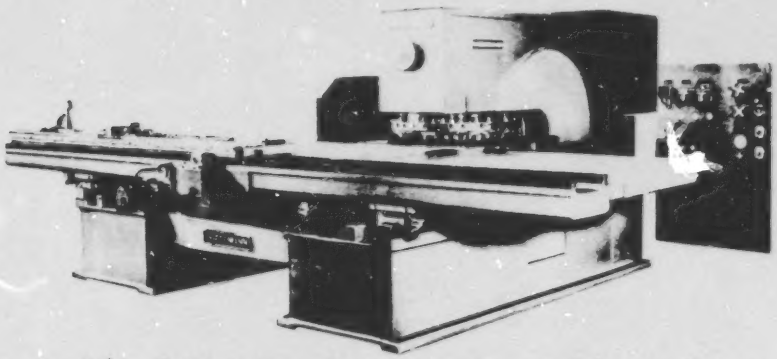

Figure 15. Turret type punching and notching machine.
(Courtesy of Weidemann Division of Warner and Swasey Company)

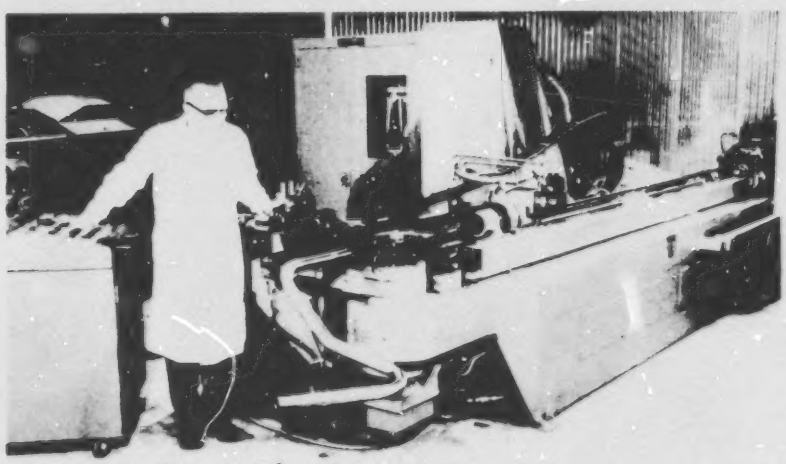

Figure 16. Tube bending machine.
(Courtesy of Teledyne Pines Company)

and permits accurate duplicates or original runs.[27] A feature of this machine is its ability to sense and measure the degree of 'material springback' in a bend and then overbend to achieve the desired angle.

Flame Cutting Machines. Numerically controlled flame cutting machines are used to cut plate stock for large fabrications, such as earth moving equipment, steel structures, bridges, ship hulls and tanks. This equipment eliminates the need for templates, scale drawings and reliance on a skilled operator to control flame cutting processes. Continuous path control directs marking, punching and scribing for layout purposes, in addition to flame and plasma arc piercing and contour cutting in steel plate.[28] An example of a bridge type N/C flame cutting machine is pictured in Figure 17. The Tape-O-Graph unit is manufactured by the Air Reduction Company with a General Electric three-axis Mark Century MCU. The Tape-O-Graph performs plate marking, straight line and contour cutting, ripping and squaring, plate edge preparation and contour beveling, as well as mirror image and dissimilar contour cutting. Both flame and plasma cutting are possible. A coordinated drive system, powered by servo motors and a rack and pinion drive, permits longitudinal and traverse motions to position simultaneously.[29]

Large fabrications such as bridges, ship hulls and tanks are designed with the aid of a computer which performs fairing of lines between points. The computer output is a machine control tape used to operate the flame cutting machine which produces smooth and accurate curved surfaces.

Welding Machines. Numerically controlled welding resulted from demands for improved standards of welding quality for aerospace activities.[30] In addition to positioning the workpiece to be welded, factors involving the welding cycle are automatically controlled. A Sciaky five-axis N/C fusion welding machine is illustrated in Figure 18. The machine consists of five main elements.

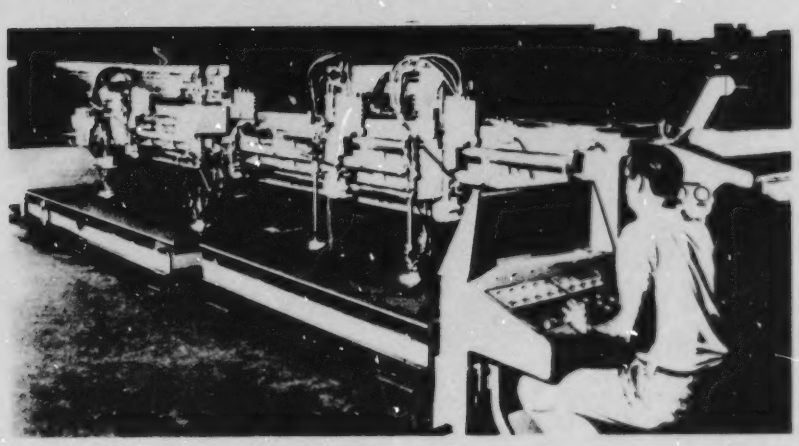

Figure 17. Flame cutting machine.
(Courtesy of Air Reduction Company)

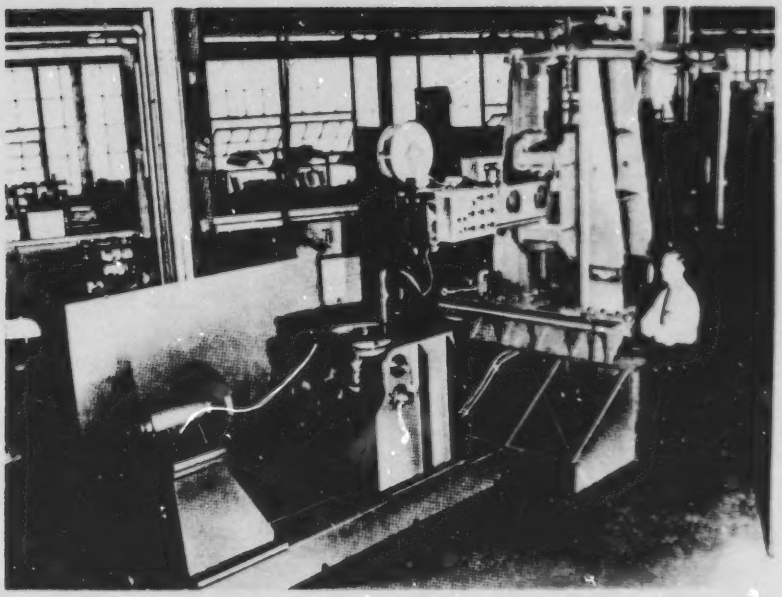

Figure 18. Fusion welding machine.
(Courtesy of Sciaky Brothers, Inc.)

One element is a traveling column ram manipulator which carries the welding head. A second is the weld positioner and tailstock unit which holds the workpiece to be welded. A third element consists of the fusion welding equipment which is under the control of the MCU. The fourth element is a servo system which employs statis solid state power amplifiers to control the current to DC drive motors. The fifth element consists of a Bendix solid state Dynapath five-axis continuous path MCU with manual and punched tape input. Machine movements in five axes and the temperature of the welding arc are controlled simultaneously by the MCU with repeatable accuracy.[31]

Filament Winding Machines. Filament winding is the technique of spinning strands of tough fibers to a desired shape over a mandrel and impregnating them with a resin to form a vessel. Taking maximum advantage of the high tensile strength of a filament permits strong, lightweight construction for a variety of vessel shapes.[32] Numerically controlled filament winding machines provide filament path and tension control during fabrication, so that the strength of the resulting vessel coincides with directional strength requirements. A representative N/C filament winding machine is pictured in Figure 19. The three-axis machine is manufactured by the Rohr Corporation and equipped with a Bunker-Ramo MCU. The machine can wind pressure vessels as much as eight feet in diameter and 13 feet long.

Component Insertion Machines. Numerically controlled component insertion machines are used in the manufacture of printed circuit boards. A component insertion machine inserts, cuts and clinches the component leads assuring proper circuit contact and improved solderability. A variety of means for supplying components to the machine are used. One method is to use an N/C device for selecting and then stringing different electrical components in proper order.[33] A

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Universal Model 2521 automatic axial lead component sequencer, manufactured by the Universal Instruments Corporation, is illustrated in Figure 20.

After a reel of components has been prepared on equipment of this type, it is loaded onto a component insertion machine which inserts the components into a circuit board. A representative component insertion machine is illustrated in Figure 21. This machine is manufactured by the Universal Instruments Corporation and is equipped with a General Electric Mark Century MCU. It positions two circuit boards simultaneously, inserts the electronic component leads into the proper holes, then cuts and clinches them.

Wire Processing Machines. Machines controlled by punched card or punched tape input media provide an accurate means of processing different sizes and types of wire from reels. Numerically controlled wire processing machines measure, mark, cut, strip and coil sections of wire so that they are ready for use.[34] A point-to-point Datex Model WPM-100 wire processing machine, manufactured by the Datex Corporation, is illustrated in Figure 22. This machine is approximately 20 feet long and is equipped with a machine control unit capable of automatic, semi-automatic or manual control.

Another process is wire wrapping, by which insulated conductor wire is automatically fastened to terminals with solderless wrapped connections. Electronic or electrical assemblies which have a modular terminal arrangement can be wired by this equipment. A representative N/C wire wrapping machine is pictured in Figure 23. This Gardner Denver Model 14F wire wrap machine was manufactured by the Gardner Denver Company. It strips insulation from one end of a wire fed from a barrel or bulk spool, wraps the end around a predetermined terminal, lays the wire along a preselected path, cuts it to length, strips the other end and wraps that end around a second terminal.[35] The machine consists of movable carriages,

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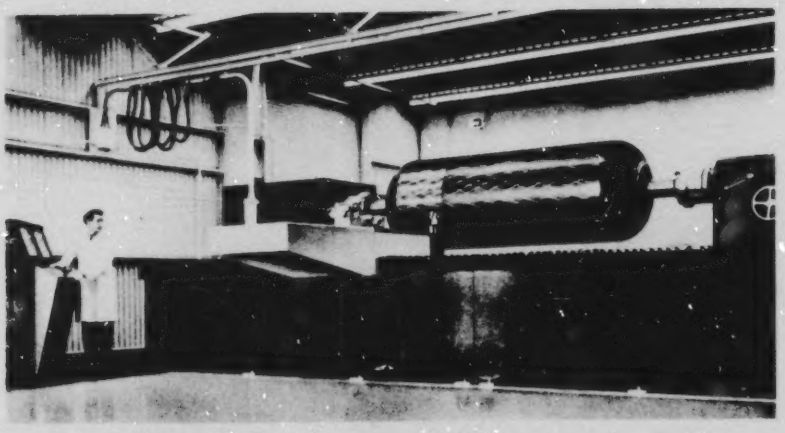

Figure 19. Filament winding machine.
(Courtesy of Rohr Corporation)

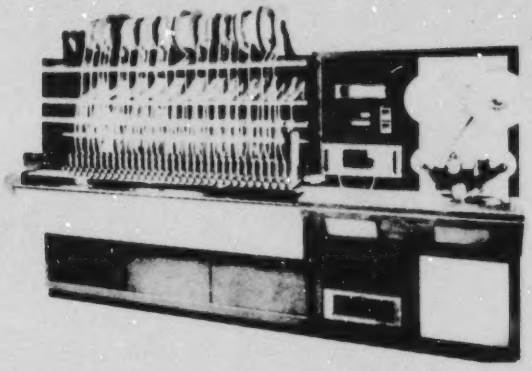

Figure 20. Component sequencing machine.
(Courtesy of Universal Instruments Corporation)

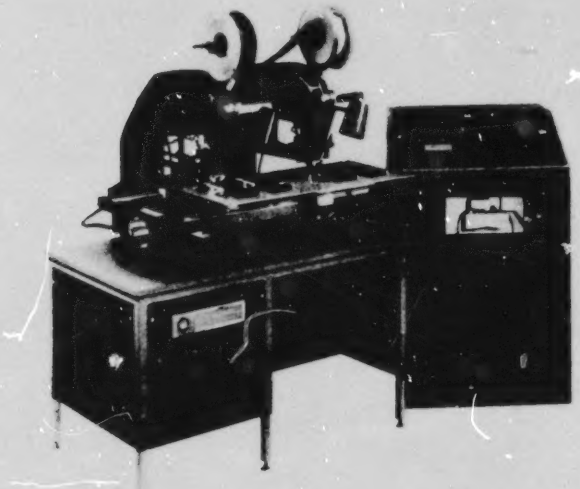

Figure 21. Component insertion machine.
(Courtesy of Universal Instruments Corporation)

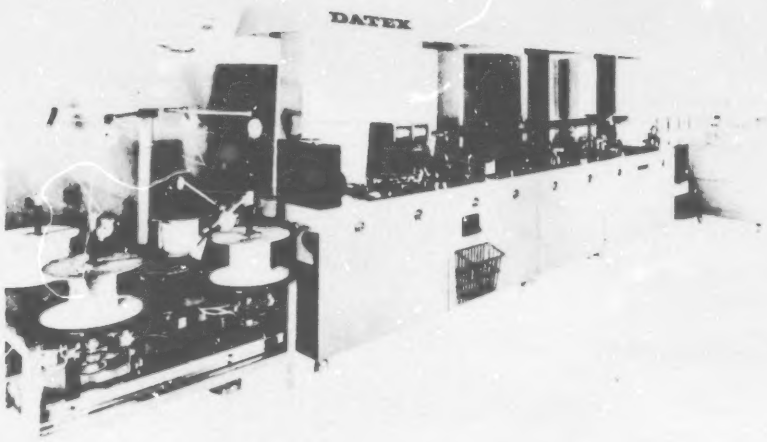

Figure 22. Wire processing machine.
(Courtesy of Datex Corporation)

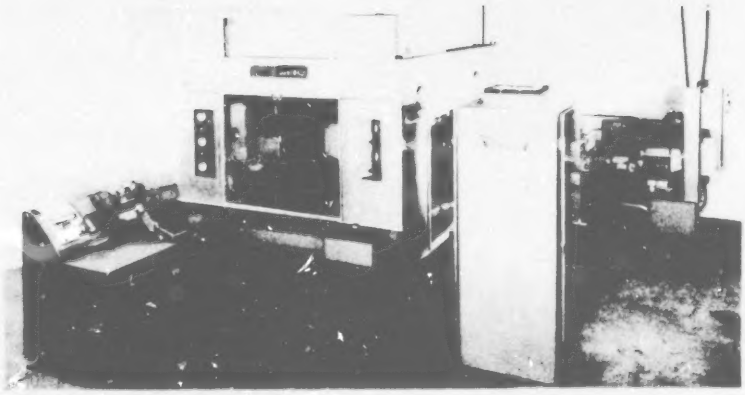

Figure 23. Wire wrapping machine.
(Courtesy of Gardner Denver Company)

containing wire wrapping tool assemblies and dressing fingers, which are positioned at modular points to give the desired wire pattern. This machine is designed so that either punched card or punched tape input media can be used for automatic operation. Fault indicating circuits are provided to facilitate constant inspection of machine performance and output during operation. Errors in programming or operation are detected, thus decreasing panel inspection time and rework.[36]

Fabric Cutting Machines. Numerically controlled fabric cutting machines provide a unique system for automatic cutting of fabrics and fabric-like materials. This equipment combines the versatility of manual cutting machines guided by an experienced cutter and the accuracy of automatic die cutting. A representative N/C fabric cutting machine is illustrated in Figure 24. The Cincinnati fabric cutting machine and Acramatic IV machine control unit are manufactured by the Cincinnati Milacron Company. The MCU controls the feed rate and the positioning of the reciprocating blade and fabric. A machine table unit, on which layers of fabric are placed, consists of two separate synchronized endless conveyor belts driven at variable speeds. A bridge which supports a movable cutting head spans the machine table.[37] An adjustable holding device under and across the bridge contains two pairs of rollers spanned by a friction pressure belt to prevent the fabric from buckling. The carriage, located under the table, provides support for the cutting blade and is synchronized with the upper carriage to control the blade through the layers of fabric. A movable cutting head contains three electric motors. One motor ensures that the cutting edge of the blade is pointed into the cut; a second motor powers an automatic blade sharpener; and the third motor drives the reciprocating blade at 3,600 motions per minute.[38]

Routers and Shapers. Numerically controlled woodworking routers and shapers are designed to provide fast cutting with high spindle speeds and feed rates. A

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representative N/C woodworking router is pictured in Figure 25. This Ekstrom Carlson #444 Rout-O-Mill equipped with a two-axis Bunker-Ramo machine control unit is manufactured by Ekstrom, Carlson and Company. All functions, such as point-to-point or continuous path cuts, spindle up or down, spindle start or stop, turret stop index to varying cutter depths, and mirror images, are controlled by the MCU. A 24 by 72 inch work table mounted on four hardened and ground guide bars holds a workpiece while a moving column and ram traverse the area. Ball nut lead screws driven by hydraulic servo-mechanisms position each motion from 0 to 400 inches per minute.[39]

Miscellaneous Production Equipment Applications. The following machines are further examples of N/C applications in production equipment:

A numerically controlled screwdriver resulted from the coupling of an automatic screwdriver with a hopper feed and a point-to-point machine control unit. This assembly is manufactured by Dixon Automatic Tools. A holding fixture mounted on an X-Y table accommodates two workpieces. The depth motion used to drive the screw is manually set.[40]

One attempt at N/C riveting employs an automatic drilling and riveting machine to fabricate aircraft fuel tanks. Manfactured by Omark Industries, the machine can accommodate airframe sections as much as 10 feet wide and 40 feet long. The N/C machine drills, countersinks and installs 16 rivets per minute. An N/C positioner rotates, elevates and tilts a workpiece to the desired angle. The machine head clamps it, drills and countersinks the proper size hole for a rivet stored in gravity hoppers. A rivet head then performs the riveting.[41]

An N/C shot-peening machine uses small hard steel shots hurled at high velocity to hammer the surface of a workpiece into compression which increases its fatigue life. The Vacu-Blast Company manufactures a five-axis N/C shot-peening

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machine. It has 25 foot travel capacity along the X axis, 5 feet along the Y axis and 5 1/2 feet along the Z axis. A boom on which the nozzle is mounted rotates 360 degrees while the nozzle itself moves 155 degrees. Various mechanical motions and the peening operation can be controlled automatically or manually by an operator at a control panel.[42]

A shearing machine controlled by N/C is manufactured by the Cincinnati Shaper Company. It is programmed by a computer which selects the best sequence and pattern to shear a given size sheet with the least amount of scrap. Computer output in punched card form is placed in the shear's card reader. Automatic control then provides for the positioning of front and back gauges, energizing probes, positioning of the delivery chute and shear cycling.[43]

An N/C coil winding machine controls wire cutting, wire placement, cementing, loading and ejection of an empty bobbin and finished coil. The MCU activates sequential or simultaneous functions and assures automatic timing, regulation of the number of turns and control of motor speeds. Coils can be programmed and encoded on punched card and punched tape input media, for more turns at one end than the other and for midcoil taps.[44] A coil winding machine manufactured by the General Electric Company counts the number of turns per coil, indexes to the next coil, counts the number of indexes and stops at the end of a cycle.

Inspection and Testing

Inspection and testing is a logical extension of N/C because it fulfills an increasing demand for improved accuracy, speed and reliability in the inspection and testing of parts manufactured by N/C production equipment.[45] The criteria for both inspection and testing with N/C are similar. In each situation the machine is programmed to measure the variable under consideration and to display or record

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the data resolved from the measurements.

Inspection Machines. Numerical control inspection is particularly advantageous where verification of the physical geometry of a workpiece is necessary or where measurement determination of the unknown geometry of a workpiece is required. An N/C inspection machine consists of a probe or sensing head, facilities for positioning and holding the workpiece to be measured, and a means of making and either displaying or recording the measurements made on the workpiece. These machines provide alignment along two horizontal axes and, in more sophisticated equipment, motions in the vertical axis as well as one or more axes of rotation of tilt.[46]

A representative N/C inspection machine is illustrated in Figure 26. This Lucas four-axis N/C inspection measuring machine was manufactured by the Lucas Machine Division of The New Britain Machine Company. It is equipped with a machine control unit which has built-in computer memory permitting programmed patterns or routines to be stored and used on command. Among these routines is one for automatic hole finding with the aid of a probe. It has the ability to determine the center, diameter and coordinate location of any hole in a workpiece and to compare this information with input data. The machine is designed to perform automatic or semi-automatic measurements of the physical dimensions of a workpiece, and record this information on a typewritten hard copy printout and/or punched tape.[47] It is capable of measuring between any two points not over 12 inches apart on one axis, with an error of ±0.0005 inch and with repeatability of ±0.0001 inch. Inspection of a known three-dimensional workpiece is accomplished by programming two axes (either manual or punched tape input) and probing the third. Inspection of an unknown three-dimensional workpiece is accomplished by providing arbitrary coordinates in the non-probe axes and probing by means of

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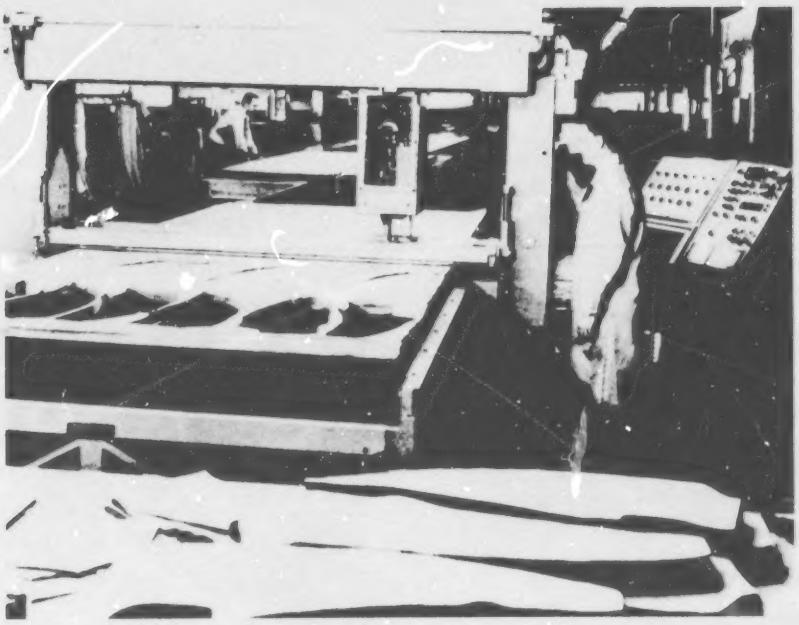

Figure 24. Fabric cutting machine.
(Courtesy of Cincinnati Milacron Company)

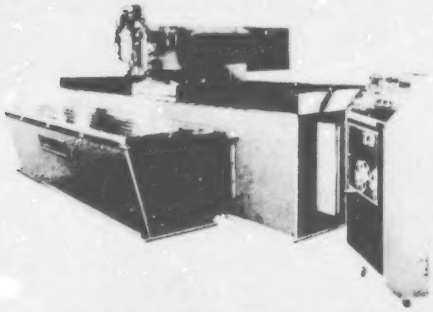

Figure 25. Woodworking router.
(Courtesy of Ekstrom, Carlson, and Company)

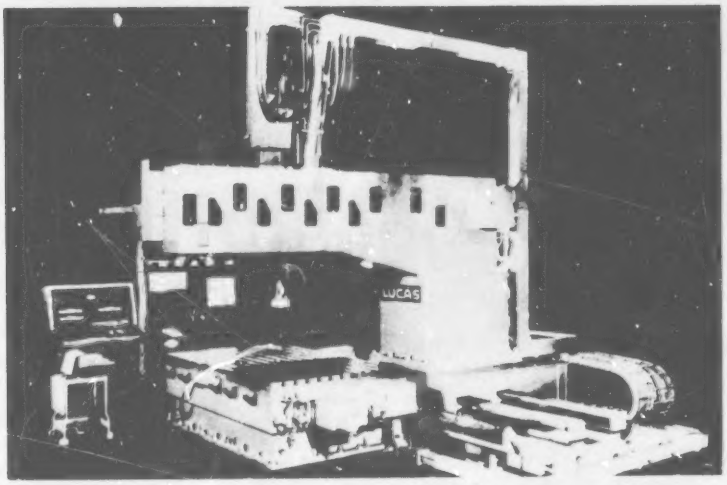

Figure 26. Inspection machine.
(Courtesy of Lucas Machine Division of The New Britain Machine Company)

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manual input in the third axis. The machine has four axes of movement: vertical, transverse, longitudinal and rotary. These axes are controlled by a closed loop electrohydraulic servo system.[48]

Testing Machines. Numerical control is used to check printed circuit boards as in the case of a pre-assembly testing operation. An N/C system requires only that a board be plugged into a module check unit. The appropriate test(s) and limits are programmed and coded on punched tape which then directs the test activity.[49]

An example of a testing machine under numerical control is a device manufactured by the Bunker-Ramo Corporation. This machine is used for inspecting printed circuit boards before they are installed in machine control units. The testing machine has a four bank console which cycles through tests under the control of punched tape input. The console makes as many as 1,500 different tests on a printed circuit board in 15 minutes. The machine goes through its testing sequence until it discovers a failure, whereupon the operator activates a repeat switch to rerun the test. Repairs can be made at this time or testing can continue with repairs to be made later. This system detects incorrect components, shorts and opens, and wiring faults in seconds. It has available supplementary testing instruments for complete analysis of any fault discovered.[50]

Summary

Operational devices identified and described under the classification of design and drafting include N/C drafting machines and N/C plotting machines. These machines are used for the preparation of drawings from mathematical descriptions, verification of tool and cutter path data on machine control input media, contour mapping, layout of printed circuit artwork masters and inspection templates, architectural drafting and automatic drafting of complex three-dimensional shapes.

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Operational devices identified and described under the classification of production equipment include numerically controlled drilling, milling, boring, turning, grinding, punching and notching, tube bending, flame cutting, welding, filament winding, component insertion, wire processing and fabric cutting machines, as well as machining centers, routers and shapers. Miscellaneous production equipment applications include screwdrivers, riveting, shot-peening and shearing machines. As the number of applications under the classification indicates, numerical control has been adopted extensively for use by production equipment.

Operational devices identified and described under the classification of inspection and testing include N/C inspection and N/C testing machines. These machines are a logical extension of N/C, because they fulfill an increasing demand for improved accuracy, speed and reliability in the inspection and testing of parts manufactured by N/C production equipment.

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APPENDIX A

GLOSSARY

This glossary presents a standardized nomenclature for numerical control. It provides operational definitions for some 214 technical words, terms, abbreviations and acronyms which form a specialized vocabulary. Entries were gathered from many sources and carry connotations not commonly found in reference dictionaries.

Numerous entries in this glossary are used in metalworking, data processing and other associated occupations. Some find their roots in the 'slang of the trade' and others have become accepted through repeated usage. However, all are defined and described as they apply to numerical control. Whenever appropriate, definitions and descriptions provided by generally recognized sources were used to minimize proliferation and duplication.

The aim of this glossary is to provide a source for arriving at some common understanding of terminology which will facilitate more exacting communication. It should therefore be useful in minimizing misunderstandings and eliminating needless debates over problems of semantics.

ABSOLUTE ACCURACY. Accuracy as measured from a reference which must be specified.

ABSOLUTE DIMENSION. (See COORDINATE DIMENSION WORD.) A dimension expressed with respect to the initial zero point of a coordinate axis.

ACCURACY. Conformity of an indicated value to the true value, i.e., an actual or an accepted standard value. (ASA C85) Measuring accuracy, precision or reproducibility: Accuracy, precision or reproducibility of position sensor or transducer and interpreting system. Control positioning accuracy, precision or reproducibility: Accuracy, precision or reproducibility of position sensor or transducer and interpreting system and including the machine positioning servo. (May be the same as machine positioning accuracy, precision or reproducibility in some systems.) Machine positioning accuracy, precision or reproducibility: Accuracy, precision or reproducibility of position sensor or transducer and interpreting system, the machine elements and the machine positioning servo. Cutter, spindle and work deflection and cutter wear are not included. (May be the same as control positioning accuracy, precision or reproducibility in some systems.) Machining accuracy, precision, or reproducibility: Accuracy, precision or reproducibility obtainable on completed parts under normal operating conditions.

ADAPT. Air Material Command Developed APT. A three-axis continuous path program written by IBM under contract with the U. S. Air Force. A general processing type of program written for small to medium sized computer whose rental would be $3,000 - $7,000 per month and whose add time would be in the order of 600 microseconds.

ADAPTIVE CONTROL. Descriptive of systems which represent an extension of closed loop, feedback control, in that performance of the machine, process or other controlled object is optimized rather than merely corrected. At present state

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of development, most adaptive machine-tool controls are special-purpose systems which sense tool torque and optimize feed-rates and speeds for small-hole drilling of extremely hard substances. Synonymous with self-optimizing control.

ADDRESS. Means of identifying information or a location in a control system. Example: The "X" command in the command X 12345 is an address identifying the numbers 12345 as referring to a position on the X axis.

AEROSPACE INDUSTRIES ASSOCIATION OF AMERICA, INC. (AIA). The national trade association of the manufacturers of aircraft, missiles, spacecraft propulsion, navigation and guidance systems, support equipment, accessories parts, and materials and components used in the construction, operation and maintenance of these products.

ALPHANUMERIC CODING. A code system in which the characters used are the letters of the alphabet and the numerals 0 to 9.

ANALOG. Denotes the use of physical variables, e.g., distance, rotation or voltage, to represent and correspond with numerical variables that occur in a computation (as opposed to digital).

ANALOG AND DIGITAL DATA. Analog data implies continuity as contrasted to digital data which is concerned with discrete states. Many signals can be used in either the analog or digital sense, the means of carrying the information being the distinguishing feature. The information content of an analog signal is conveyed by the value or magnitude of some characteristics of the signal such as the amplitude, phase or frequency of a voltage, the amplitude or duration of a pulse, the angular position of a shaft or the pressure of the fluid. To extract the information, it is necessary to compare the value or magnitude of the signal to a standard. The information content of a digital signal is concerned with discrete states of the signal, such as the presence or absence of a voltage, a contact in the

open or closed position, or a hole or no hole in certain positions on a card. The signal is given meaning by assigning numerical values or other information to the various possible combinations of the discrete states of the signal.

APT. An abbreviation of Automatic Programmed Tools. APT is a computer-based Numerical Control programming system which uses English-like symbolic descriptions of part and tool geometry, and tool motion.

ASA. American Standards Association.

ASCII. American Standard Code for Information Interchange.

ASSEMBLE. To integrate subroutines into the main routine by adapting or changing relative and symbolic addresses to absolute form.

AUTOMAP. AUTOmatic MAchining Program. A computer language by which an object can be described from an engineering drawing. The general descriptive statements are translated by the AUTOMAP program into detailed instructions required to direct the action of the machine tools. Two-dimensional limitation and proprietary with IBM.

AUTOMATION. The investigation, design, development and application of methods of rendering processes self-controlling through feedback analysis.

AUXILIARY FUNCTION. A function of a machine other than the control of the coordinates of a workpiece or tool. Includes functions such as miscellaneous, feed, speed, tool selection, etc. Not a preparatory function.

AUXILIARY FUNCTION WORD. A word used to command auxiliary actions such as coolant on or off.

AXIS. (1) One of the lines of direction or motion on a machine. (2) One of the reference lines of a coordinate system.

BACKLASH (ASA C85). A relative movement between interacting mechanical parts resulting from looseness.

BASE-LINE DIMENSIONING. Descriptive of designing and part drawing technique of recording dimensions as distances from a base line, which may be outside the part, in order to reduce duplication of effort and simplify mathematical tasks of numerical control part programmers.

BED. Fixed portion of machine structure which may provide a work mounting surface and will support other machine elements (table, ways, column, saddle, gantry, etc.).

BINARY CODE. A code in which each allowable position has one of two possible states. A common symbolism for binary states is 0 and 1. The binary number system is one of many binary codes.

BINARY-CODED-DECIMAL SYSTEM (BCD). A system of number representation in which each decimal digit is represented by a group of binary digits forming a character.

BINARY DIGIT. A digit in the binary scale of notation. This digit may be only 0 (zero) or 1 (one). It is equivalent to an 'on' condition or an 'off' condition, a 'yes' or a 'no', etc.

BINARY NOTATION. The writing of numbers in the scale of two. The first dozen numbers zero to eleven are written 0, 1, 10, 11, 100, 101, 110, 111, 1000, 1001, 1010, 1011. The position of the digits designate powers of two; thus 1010 means 1 times two cubed or eight, 0 times two squared or 4, 1 times two to the first power or two, and 0 times two to the zero power or one; this is equal to one eight plus no four's plus one two plus no one's, which is ten.

BIT. (1) An abbreviation of 'binary digit'. (2) A single character of a language employing exactly two distinct kinds of characters.

BLOCK. A word or group of words considered as a unit and separated from other such units by an End of Block character.

BLOCK ADDRESS FORMAT. Means of identifying words by use of an address specifying the format and meaning of the words in a block.

BLOCK READER. A tape reader which will read a complete block of information at the same time.

BUFFER STORAGE. An intermediate storage medium between data input and active storage.

BYTE. A sequence of binary digits usually operated upon as a unit.

CANCEL. A command which will discontinue any fixed cycles or sequence commands.

CARD-TO-TAPE CONVERTER. A device which converts information directly from punched cards to punched or magnetic tape.

CARTESIAN COORDINATE. (1) The distance of a point from either of two intersecting straight-line axes measured parallel to the other axis. (2) The distance from any of three intersecting coordinate planes measured parallel to that one of three straight-line axes that is the intersection of the other two planes.

CHARACTER. One of a set of elementary marks or events which may be combined to express information. Example: The characters normally used in numerical control include those representing the decimal digits 0 to 9, the letters of the alphabet, and special characters such as Tab, End of Block, and End of Record.

CHIPMAKING. The cutting away of excess metal, in the form of chips, from a workpiece by use of a cutting tool. Differentiated from abrading or grinding be[illegible] of the larger sizes of chips removed and by higher metal-removal rates.

[illegible]RCULAR INTERPOLATION. A mode of contouring control which uses the inf[illegible]mation contained in a single block to produce an arc of a circle. The velocities of the axes used to generate this arc are varied by the control.

CLOSED LOOP SYSTEM. A system in which the output, or some result of the output, is fed back for comparison with the input, for the purpose of reducing the difference.

CODE. A system of signals or characters and rules for their interpretation. For punched or magnetic tape, a predetermined arrangement of possible locations of holes or magnetized areas and rules for interpreting the various possible patterns.

CODED-DECIMAL CODE. The decimal number system with each decimal digit expressed by a code.

COMMAND. (1) An electronic pulse, signals, or set of signals to start, stop or continue some operation. It is incorrect to use command as a synonym for instruction. (2) That portion of an instruction word which specifies the operation to be performed.

COMPARATOR CIRCUIT. A circuit which compares two signals and supplies an indication of agreement or disagreement.

COMPATIBILITY. The degree to which tapes, languages and programming can be interchanged among various machine tools and N/C systems.

COMPILER. A computer program more powerful than an assembler. In addition to its translating function, which is generally the same process as that used in an assembler, it is able to replace certain items of input with series of instructions, usually called subroutines. Thus, where an assembler translates item for item, and produces as output the same number of instructions or constants which were put into it, a compiler will do more than this. The program which results from compiling is a translated and expanded version of the original.

COMPUTER. A device capable of accepting information, applying prescribed processes to the information, and supplying the results of these processes. It usually consists of input and output devices, storage, arithmetic and logical units,

and a control unit.

CONTINUOUS DATA. Data of which the information content can be ascertained continuously in time.

CONTINUOUS PATH. A type of N/C machine operation in which rate and direction of relative movement of machine members is under continuous control.

CONTOURING CONTROL SYSTEM. A system in which the controlled path can result from the coordinated, simultaneous motion of two or more axes.

CONTROL CIRCUITS. The circuits which effect the carrying out of instructions.

CONTROLLER. An apparatus of unitized or sectional design, through which commands are introduced and manipulated. A program controller has the following functions; data, computation, encoding, storage, readout, process computation and output.

COORDINATE DIMENSION WORD. A word defining an absolute dimension.

COORDINATES. Positions or relationships of points or planes.

CORE MEMORY. A programmable, random-access memory consisting of many ferromagnetic cores strung on wires in matrix arrays.

CUTTER COMPENSATION. Displacement, normal to the cutter path, to adjust for the difference between actual and programmed cutter radii or diameters.

CYBERNETICS. The field of technology involved in the comparative study of the control and intracommunication of information-handling machines and nervous systems of animals and man in order to understand and improve communication.

CYCLE. A set of operations performed in predetermined manner.

DATA. Any facts or information particularly as taken in, operated on, or put out by a machine for handling information.

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DATA HANDLING SYSTEM. Automatic handling such as sorting, decoding or storing of information in desired form. Sometimes called data reduction system.

DATA PROCESSING. The transition of numerically descriptive engineering and manufacturing data into a form suitable for machine control.

DEBUG. (1) To locate and correct any errors in a computer program or part program. (2) To detect and correct malfunctions in a computer, control system or machine.

DECADE. A group or assembly of ten units; e.g., a counter which counts to ten in one column or a register box which inserts resistance quantities in multiples of powers of ten.

DECIMAL CODE. A code in which each allowable position has one of 10 possible states. The conventional decimal number system is a decimal code.

DECIMAL DIGIT. One of the symbols 0 through 9 when used in numbering in the scale of ten.

DECODING. Translation from a coded form to an analog or other easily recognized form, without significant loss of information.

DIGITAL. Refers to discrete states of a signal (i.e., either on or off). Since a combination of on-off signals make up a specific value, the magnitude of each signal is irrelevant. The theoretical extent of accuracy of a digital system is therefore unlimited and will depend on the amount and cost of electronics involved. Numerical control systems may be of analog, digital or combination analog-digital type of construction.

DIGITAL COMPUTER. A computer which processes information represented by combinations of discrete or discontinuous data as compared with an analog computer for continuous data. More specifically, it is a device for performing sequences of arithmetic and logical operations, not only on data but its own

program. Still more specifically, it is a stored program digital computer capable of performing sequences of internally stored instructions, as opposed to calculators, such as card programmed calculators, on which the sequence is impressed manually.

DIGITIZE. The conversion of analog to digital data. (A/D).

DIGITIZING MACHINE. A machine, similar in appearance to automatic drafting machine, which senses lines and curves on graphic input, such as an engineering mechanical drawing, and converts to numerical tape and/or printed output. May be operated by programming personnel who type auxiliary machine-tool commands for merger with geometric data such as cutter center-paths, to produce complete machine control tapes for numerical machining. May be automatic drafting machine with additional equipment which permits digitizing.

DISCRETE UNITS. Distinct units of a digital nature, as opposed to a continuous information flow which is analog.

DOWNTIME. The period during which a system, computer or any other device is malfunctioning or not operating, due to electronic, mechanical or other inherent failure.

DWELL. A timed delay of programmed or established duration, not cyclic or sequential, i.e., not an interlock or hold.

EIA STANDARD CODE. A standard code for positioning, straight-cut and contouring control systems proposed by the U.S. Electronic Industries Association in their Standard RS-244. It uses eight-track paper tape, one inch wide, and is known as 8-B code. It has been recognized by the German V.D.I. and may possibly become a universal standard. It has recently been accepted by the American Standards Association as an American standard for numerical control.

ELECTRONIC DATA PROCESSING (EDP) SYSTEM. The general term used to define a system for data processing by means of machines utilizing electronic circuitry at electronic speed, as opposed to electromechanical equipment.

ELECTRONIC INDUSTRIES ASSOCIATION (EIA). A national trade association representing manufacturers of electronic parts, equipment and systems for consumer, industrial and military applications. The subject of numerical control is one of many within the electronics area.

ELECTRONIC SWITCH. A circuit element causing a start and stop action or a switching action electronically, usually at high speed.

ENCODING. Translation to a coded form from an analog or other easily recognized form, without significant loss of information.

END OF BLOCK SIGNAL. A symbol or indicator that defines the end of one block of data.

END OF PROGRAM. A miscellaneous function indicating completion of workpiece. Stops spindle, coolant and feed after completion of all commands in the block. Used to reset control and/or machine. Resetting control may include rewind of tape or progressing a loop tape through the splicing leader. The choice for a particular case must be defined in the format classification sheet.

END OF TAPE. A miscellaneous function which stops spindle, coolant and feed after completion of all commands in the block. Used to reset control and/or machine. Resetting control will include rewinding of tape, progressing a loop tape through the splicing leader or transferring to a second tape reader. The choice for a particular case must be defined in the format classification sheet.

END-POINT CONTROL. Quality control through continuous automatic analysis. The final product is analyzed and the process changed if there are undesirable variations.

ERROR COUNTER or ERROR REGISTER. This is a device for accumulating and signaling the algebraic difference between desired machine movement and the actual movement of the machine.

ERROR SIGNAL. A signal inside a closed-loop system representing the difference between desired position and actual position.

EXTERNAL MEMORY. A storage medium outside the system, such as a punched or a magnetic tape.

FEED FUNCTION. The relative velocity between the tool or instrument and the work due to motion of the programmed axis (axes).

FEED RATE BY-PASS. A function directing the control system to ignore programmed feed rate and substitute a selected operational rate.

FEED-RATE NUMBER. A number read from the tape, governing the rate at which command pulses are emitted from the interpolator.

FEED RATE OVERRIDE. A manual function directing the control system to modify the programmed feed rate by a selected multiplier.

FEEDBACK LOOP. The part of a closed loop system which provides controlled response information allowing comparison with a referenced command.

FIXED BLOCK FORMAT. A format in which the number and sequence of words and characters appearing in successive blocks is constant.

FIXED CYCLE or CANNED CYCLE. A preset series of operations which direct machine axis movement and/or cause spindle operation to complete such action as boring, drilling, tapping or combinations thereof.

FIXED SEQUENTIAL FORMAT. Means of identifying a word by its location in the block. Words must be presented in a specific order and all possible words preceding the last desired word must be present in the block.

FIXED WORD-LENGTH. Having the property that a machine word always contains the same number of characters or digits. Contrasted with variable word-length.

FLOATING ZERO (See ZERO OFFSET). A characteristic of a numerical machine control permitting the zero reference point on an axis to be established readily at any point in the travel. The control retains no information on the location of any previously established zeros.

FORMAT. A systematic arrangement of data. A applied to tape or cards, the rules defining the position of the bits. As applied to manuscripts, the rules defining the structure of the information.

FORMAT CLASSIFICATION. A means, usually in an abbreviated notation, by which the motions, dimensional data, type of control system, number of digits, auxiliary functions, etc. for a particular system can be denoted.

G FUNCTION. A preparatory code on a program tape to indicate a special function. The 'g' is actually a lower case letter when shown on a printout. For example: g90 indicates that the following coordinate locations are expressed in absolute dimensions and g91 indicates they will be expressed incrementally. Of course such functions would only be utilized on machine control units having the capabilities called for by the function.

GRAPHIC PANEL. A master control panel which, pictorially and usually colorfully, traces the relationship of control equipment and the process operation. It permits an operator at a glance, to check on the operation of a far flung control system by noting dials, valves, scales and lights.

GRATING. Gratings provide a method of measuring from one point to another. The movement between a pickup cell and an optical grating produce variations in the intensity of light on a multiple photosensitive device. These are

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converted into electrical pulses which are counted and fed back as data into the basic control system. The ambiguity between the counts produced and the counts commanded can be diminished to zero as a slide is positioned to its predetermined point.

HARD COPY. Any form of computer-produced document. Also, punched cards or paper tape.

HARDWARE. The physical component parts of a machine control unit or computer. See also SOFTWARE.

HEAD. A device which reads, records or erases information in a storage medium - usually a small electro-magnet used to read, write or erase information on a magnetic drum or tape, or the set of perforating or reading fingers and block assembly for punching or reading holes in paper tape or cards.

HOLD. An untimed delay in the program, terminated by an operator or interlock action.

INCREMENT. The value which is added to a coordinate dimension to produce a change.

INCREMENTAL DIMENSION or DELTA DIMENSION. A dimension expressed with respect to the preceding point in a sequence of points.

INCREMENTAL FEED. A manual or automatic input of preset motion command for a machine axis.

INDUCTOSYN. Trade name for linear and rotary feedback devices manufactured by Farrand Controls, Inc.

INPUT. Transfer of external information into the control system.

INPUT EQUIPMENT. The device which takes outside information into a machine.

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INSTRUCTION STORAGE. Storage media containing basic machining instructions in coded form.

INTEGRATED CIRCUITS. Also known as IC's. A very small single structure assembly of electronic components containing many circuits and functions. Modern computers and machine control units are made with IC's instead of transistors or vacuum tubes.

INTERFACE. The medium by which two separate elements are joined. There is an interface between machine control unit and machine tool comprised of electrical circuitry and drive motors. If a computer directly controls a machine tool there is an appropriate interface.

LAG. A relative measure of the time delay between two events, states or mechanisms.

LANGUAGE. The association or rule which is used to represent code information.

LEAD SCREW. An extremely accurate threaded shaft used to convert rotation to longitudinal motion.

LEADER. The section of tape which appears ahead of and after a section of coded tape. When producing leader by punching tape feed, sprocket holes are produced. It may also include a parity code.

LINEAR INTERPOLATION. A mode of contouring control which uses the information contained in a block to produce velocities proportioned to the distance moved in two or more axes simultaneously.

LOGIC. (1) The systematic scheme which defines the interactions of signals in the design of an automatic data processing system. (2) The basic principles and application of truth tables and inter-connection between logical elements required for arithmetic computation in an automatic data processing system.

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M FUNCTION. Similar to a 'g' function except that the 'm' functions control miscellaneous functions of the machine tool such as turning on and off coolant or operating power clamps and so on.

MACHINE ACTUATOR or MACHINE SERVOMOTOR. A power device for directly effecting machine motion.

MACHINE CONTROL UNIT (MCU). Synonymous with numerical control system in its hardware form. Sometimes referred to as the 'director' or 'controller'.

MAGNETIC TAPE. A tape or ribbon of any material impregnated or coated with magnetic or other material on which information may be placed in the form of magnetically polarized spots.

MANUAL DATA INPUT. A means for the manual insertion of numerical control commands.

MANUAL MODE. A method of operation where data is entered manually by dial or other means instead of by program tape. A machine may be entirely program controlled, it may have certain functions which are done manually or in some instances it may be entirely under manual operation.

MANUSCRIPT (See PROGRAMMING). An ordered list of numerical control instructions.

MIRROR IMAGE PROGRAMMING. A feature of some machine control units that provides for the reversing of all instructions programmed for a specific axis (usually X) by means of a switch. This means that a single program tape can produce two mirror image parts.

MIXED SEQUENTIAL FORMAT. A format in which a word is identified by its location in the block. Words must be presented in a specific order, and all possible words preceding the last desired word must be present in the block.

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NATIONAL AEROSPACE STANDARDS (NAS). A series of AIA-developed standards covering such aerospace hardware as fasteners, fittings and electrical items; specifications for aerospace materials, packaging materials and machine tools; and testing procedures. Approximately one hundred standards were issued or revised in 1966. The year 1967 marked its twenty-fifth anniversary.

NMTBA. National Machine Tool Builders Association.

NOISE. A term used to describe stray electrical impulses that can disturb the normal operation of a machine control unit or computer.

NUMBER SYSTEMS. Position notation. A systematic method for expressing numerical data.

NUMERICAL CONTROL SYSTEM. A system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of this data.

NUMERICAL DATA. Data in which information is expressed by a set of numbers or symbols that can only assume discrete values or configurations.

OFF-LINE OPERATION. Usually applies to peripheral equipment which operates indepencently of the central computer. This equipment is generally utilized where it is not necessary to operate the full capabilities of the major portion of the computer, thus saving time and expense.

ON-LINE OPERATION. Applies to computer operations and calculations which are performed by the computer itself or the major portion of the computer.

OPEN LOOP SYSTEM. A control system that has no means for comparing the output with input for control purposes.

OPERATION NUMBER. A number indicating the position of an operation in performance sequence.

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OVERSHOOT. Occurs when results exceed the target value.

PAPER TAPE. A strip of paper capable of storing or recording information. Storage may be in the form of punched holes, partially punched holes, carbonization or chemical change of impregnated material, or by imprinting. Some paper tapes, such as punched paper tape, are capable of being read by the input device of a computer or a transmitting device by sensing the pattern of holes which represent coded information.

PARABOLIC INTERPOLATION. A high order of interpolation producing contoured shapes by having the cutting tool travel through parabolas or portions of parabolas. This method of interpolation is particularly applicable to mold or die work where free form shapes can be generated with a minimum number of program steps.

PARITY CHECK. A means of determining whether a character has an odd or an even set of marks to describe it. Usually characters in a code are all odd or even. An extra "parity mark" is added to make this the case.

PART PROGRAMMING, COMPUTER. The preparation of a manuscript in computer language and format required to accomplish a given task. The necessary calculations are to be performed by the computer.

PART PROGRAMMING, MANUAL. The preparation of a manuscript in machine control language and format required to accomplish a given task. The necessary calculations are to be performed manually.

PATCH. A section of coding inserted into a routine to correct a mistake or alter the routine.

PATH STORAGE. Storage media containing interpolated path of tool and instructions for auxiliary functions.

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PERFORATED TAPE. Tape in which a code hole(s) and a tape feed hole have been punched in a row.

PERIPHERAL EQUIPMENT. The auxiliary machines which may be placed under the control of the central computer. Examples of this are card readers, card punches, magnetic tape feeds and high-speed printers. Peripheral equipment may be used on-line or off-line depending upon computer design, job requirements and economics.

POLAR COORDINATE. Either of two numbers that locate a point in a plane by its distance from a fixed point on a line and the angle this line makes with a fixed line.

POSITION STORAGE. Storage media containing major positions of tool and instructions for auxiliary functions.

POSITIONING CONTROL SYSTEM or POINT-TO-POINT CONTROL SYSTEM. A system in which the controlled motion is required only to reach a given end point, with no path control during the transition from one end point to the next.

POST PROCESSOR. A set of computer instructions which transform tool centerline data into machine motion commands using the proper tape code and format required by a specific machine/control system. Instructions such as feedrate calculations, spindle speed calculations and auxiliary function commands may be included.

PREPARATORY FUNCTION. A command changing the mode of operation of the control such as from positioning to contouring or calling for a fixed cycle of the machine.

PRINTER. An output mechanism which prints or typewrites characters.

PRINTOUT. A printed sheet giving all the data of a program that has either been manually or computer processed. The printout is used for reference and

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visual checking. Normally the printout will be made at the same time a tape is punched.

PROCESS CONTROL. Descriptive of systems in which digital, analog or hybrid computers are used for the automatic regulation of operations or processes. Typical are operations in the production of chemicals wherein the operation control is applied continuously and adjustments to regulate the operation are directed by the computer to keep the value of a controlled variable constant.

PROGRAM STOP. A miscellaneous function command to stop the spindle, coolant and feed after completion of other commands in the block. It is necessary for the operator to push a button in order to continue with the remainder of the program.

PROGRAMMER (COMPUTER PROGRAMMER). A person who prepares computer programs which are to be used internally in the computer in order to solve the specific problems presented by the part programmer. A numerical control computer programmer generally requires a formal advanced mathematical background in addition to a thorough knowledge of computer operations.

PROGRAMMER (PART PROGRAMMER). A person who prepares the planned sequence of events for the operation of a numerically controlled machine tool. The programmer's principal tool is the manuscript on which the instructions are recorded.

PROGRAMMING. The ordered listing of a sequence of events designed to accomplish a given task.

PROTOTYPE. A first, or original, model which, after testing and refining, is the basis for the final product.

PULSE. A pattern of variation of a quantity, such as voltage or current, consisting of an abrupt change from one level to another, followed by an abrupt

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change to the original level.

PUNCH CARD. A card of constant size and shape, suitable for punching in a pattern that has meaning, and for being handled mechanically. The punched holes are usually sensed electrically by wire brushes or mechanicaly by fingers.

PUNCHED TAPE. Paper tape punched in a pattern of holes so as to convey information.

RADIX. Base or root. A number that is arbitrarily made the fundamental number of a number system. The quantity of different symbols required to express any integer in a number system.

RANDOM ACCESS. Indicates equality of access time to all memory locations, without dependence on the location of the previous memory reference.

RAW STORAGE. Storage media, such as drawings, containing all information (geometry of part, cutter size, feeds and speeds, etc.) necessary for preparation of the manuscript.

READ. To sense the characters numerical input information such as performed by input equipment.

READOUT, POSITION. Display of absolute position as derived from a position transducer.

REAL TIME. The ability of a computer to function and control a process as that process occurs. For example: a computer directly controlling the operation of a machine tool would be a real time application. If a computer generates a program tape and the tape is utilized at some later time, the computer has been used in an "off-line" application.

REFERENCE BLOCK. A block within the program identified by an "o" (letter o) in place of the word address "n" and containing sufficient data to enable resumption of the program following an interruption. This block should be located

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at a convenient point in the program which enables the operator to reset and resume operation.

RESOLUTION. (ASA C85). The least interval between two adiacent discrete details which can be distinguished one from the other.

RETROFIT. To take a conventional machine tool and to outfit it with numerical controls. It is not an original designed NCMT and performs as a retrofit. Most retrofits do not reach the peaks of efficiency as a true designed-from-scratch NCMT.

ROUTINE. A set of coded instructions, supplied to a general purpose computer, which established a sequence of operations to be followed in the logical processing of a class of data.

ROW. A path perpendicular to the edge of a tape along which information may be stored by presence or absence of holes or magnetized areas.

SCANNER. an instrument which checks a number of measuring points in some sequence.

SENSITIVITY. The ability of a device or system to respond to its smallest command.

SEQUENCE NUMBER. A number identifying the relative location of blocks or groups of blocks on a tape.

SEQUENCE NUMBER READOUT. Display of the sequence number punched on the tape.

SEQUENTIAL. Arranged in some predetermined logical order.

SERIAL OPERATION. Type of information transfer within a digital computer whereby all digits of a word are handled sequentially rather than simultaneously.

SERVOMECHANISM (ASA C85). An automatic feedback control system in which the controlled variable is mechanical position or any of its time derivatives.

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SIGN DIGIT. A plus or a minus to designate the positive or negative characteristic or a coordinate.

SKIP. An instruction to proceed to the next instruction. See also Tab.

SOFTWARE. All of the program manuscripts, tapes, decks of tabulating cards, methods sheets, flow charts and other programming documentation associated with computers and N/C. Its counterpart is the physical hardware comprising the computer or N/C system.

SOLID STATE. The logic of a computer or machine control unit made solely of solid-state electronic components. There are no relays, vacuum tubes and so on.

SPECIFIED CUTTING TOLERANCES. Allowable deviations of measurement of a test part or parts from the programmed dimension, which may result from control error, machine deflection, backlash in slides, cutter runout, cutter deflection and the like.

SPINDLE SPEED. The rate of rotation of the machin spindle usually expressed in terms of RPM.

STORAGE CAPACITY. The amount of data, usually expressed as the number of words, which can be retained in a storage or memory unit.

STORAGE MEDIUM. Any device or recording medium into which data can be stored and held until some later time, and from which the entire original data can be obtained.

STRAIGHT CUT CONTROL SYSTEM. A system in which the controlled cutting action occurs only along a path parallel to linear, circular or other machine ways.

SUBROUTINE. A portion of the total N/C program, stored in the computer's memory, and available upon call to accomplish a particular operation, usually a mathematical calculation. At its conclusion, control reverts to the master routine.

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SYNCHRO. Any member of a family of wound rotor magnetic induction transducers (known as selsyns, autosyns and telesyns) that are capable of electrically transmitting and receiving angular position information.

T FUNCTION. A code identifying a tool select command on a program tape. As with 'm' and 'g' codes, the 't' also appears as a lower case letter on a printout.

TAB. A non-printing spacing action on typewriters and tape preparation devices whose code is necessary to the tab sequential format.

TAB SEQUENTIAL FORMAT. Means of identifying a word by the number of tab characters preceding the word in the block. The first character in each word is a tab character. Words must be presented in a specific order but all characters in a word, except the tab character, may be omitted when the command represented by that word is not desired.

TAPE FEED. A mechanism which will feed tape to be read or sensed by the machine.

TAPE PREPARATION. The act of translating command information into punched or magnetic tape.

TEMPORARY STORAGE. Internal storage locaitons reserved for intermediate and partial results.

TIME-SHARING. The use of a device for two or more purposes during the same overall time interval, accomplished by interspersing component actions in time.

TOOL FUNCTION. A command identifying a tool and calling for its selection either automaticaiiy or manually. The actual changing of the tool may be initiated by a separate tool change command.

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TOOL OFFSET. A correction for tool position parallel to a controlled axis.

TRACK (Formerly Channel or Level). A path parallel to the edge of a tape along which information may be stored by presence or absence of holes or magnetized areas.

TRANSDUCER. A device for changing one form of energy into another form, for example, from an electrical signal into mechanical motion, as in a relay.

TRAVEL. The distance moved between two points on a machine axis, usually given in inches.

UNITED STATES OF AMERICA STANDARDS INSTITUTE (USASI). On August 24, 1966, the ASA was reconstituted as the United States of America Standards Institute. This is a non-profit organization which works with U.S. industry to establish national (sometimes international) standards as guides to aid the manufacturer, the user and the general public.

VARIABLE BLOCK FORMAT. A format which allows the number of words in successive blocks to vary.

VARIABLE WORD-LENGTH. Having the property that a machine word may have a variable number of characters. Contrasted with fixed word-length.

VERIFY. To check, usually automatically, one typing or recording of data against another in order to minimize human and machine errors in the punching of tape or cards.

WORD. An ordered set of characters which is the normal unit in which information may be stored, transmitted or operated upon. Example: The set of characters 10692 is a word which may give a command for a machine element to move to a point 10.692 inches from a specified zero.

WORD ADDRESS FORMAT. Addressing each word of a block by one or more characters which identify the meaning of the word.

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X-Y PLOTTER. A device used in conjunction with a computer to plot coordinate points in the form of a graph.

ZERO OFFSET (See FLOATING ZERO). A characteristic of a numerical machine control permitting the zero point on an axis to be shifted readily over a specified range. The control retains information on the location of the 'permanent' zero.

ZERO RESET. The ability to realign automatically each axis slide to the zero or target point by pressing a button when the slides are brought within close proximity of the target point.

ZERO-SUPPRESSION. The elimination of non-significant zeros to the left of the integral part of a quantity before printing is begun.

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